RUDIMENTARY TREATISE

ON THE

DRAINAGE

OF

DISTRICTS AND LANDS.

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"THE PRACTICAL RAILWAY ENGINEER,"
ETC. ETC. ETC.

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A REVISED AND GREATLY EXTENDED EDITION OF

PART II.—On the "Drainage of Towns and Buildings," is in the press, and will be published shortly.

PREFACE TO THE FIRST EDITION.

A FEW years since, the subject of the following volume would have been considered scarcely a necessary theme for one of a series of works intended to bear a popular as well as a technical character. The entire subject would have been deemed sufficiently disposed of by describing the subterranean works of the navigator and the bricklayer, and the sub-aquatic and rude operations of the ditcher. Now, however, our subject occupies a prominent position in the public thought, and may be regarded as nearly a new branch of practical art, based, or to be based, upon principles of science, and essential to the health, life, and morality of our race.

Urged, almost insensibly, by the strong earnestness and foresight of a few leading minds, the British public and Legislature have been brought to discern the urgent need of reforming the substructures of their dwellings and highways, and to feel affrighted at the dangerous apathy in which they and their ancestors have hitherto innocently indulged. The rudeness of our past practice is indeed the subject of our astonishment; the facts adduced are but the pictures of our individual experience, and the simplicity of the principles now first recognised brings them home to us with all the familiarity of things known long ago. We

now wonder at the folly of digging holes beneath houses for the accumulation of filth, till the surrounding ground becomes overcharged, and the bulk demands periodical removal. We can see clearly enough that the pursuits of the scavenger are offensive equally to common sense and to common decency, and admit, without further proof, the sanatory axiom, that the infusion of the refuse of a town in the water which serves at once the libations and ablutions of its people, is *not* adapted either to perfect the purity of the liquid, or promote the health of the human system. And in that great branch of the subject which is devoted to agricultural practice, by which the farmer is endowed with all the valuable experience of the most intelligent inquirers, and taught the art of economising the natural resources of his streams and watercourses, and the fructifying products of his farm-yard, Drainage has acquired a well-recognised value in the estimation of the scientific public, and is daily recording results of the highest practical character.

The general principles which are now commonly entertained upon the subject of Drainage, maintain its primary value as a branch of sanatory science, and its claim to be regarded among the paramount duties of every civilised Legislature. District Commissions are disbanded as incapable of achieving the great purposes which the health of the people demands, and which can no longer be entrusted in the hands of incompetent authorities. Cleanliness and health are now considered in the relation of cause and effect; and the first requirements of the physician's success are admitted to consist in the constructive conditions of the patient's dwelling. Medical philanthropists have explored the hidden horrors of our metropolis and towns, and shown that the open sewer and the offal heap are the

contaminators of the rich, and the agents of death to the poor. And, akin to these public pestilences, we are now made aware that a cesspool, or an imperfect drain in a house, is to be reckoned only as a means of gathering fever and disease; and that the cleansing of the rooms above, while one of these radical abominations is sending forth its putrid gases from below, is but an illustration of the ancient error of rectifying secondary, in mistake for primary, evils.

While thus the subject of Drainage is attaining a commanding importance among the social necessities of our times, a corresponding occasion has arisen for its thorough examination as a branch of practical science. Its principles are, or must be, determined, and its rules thence deduced and embodied among the vital applications of the useful arts. The future works of the engineer, the architect, and the builder, must be regulated by considerations of the available methods of securing ample water-supply and efficient drainage; and these considerations will present themselves with that imperative character which they derive from the public will, and which cannot be countervailed by any scruples of private economy, or any opposition of corporate prejudice.

To collect carefully the records of the experience of the past, to compare results and deduce principles with critical anxiety, and upon these principles to establish practical rules, propounded and illustrated with exactness and fidelity, will doubtless become the common object of many of the students of practical art. The following elementary treatise cannot attempt so extensive and laborious a range, but it aims at accomplishing a general survey of the subject, and a brief enumeration of the details which properly belong to it.

PREFACE TO THE SECOND EDITION.

In the Introduction to the first edition of this little book, a congratulation was ventured upon the interest in its subject taken by the public at that time. That that interest is still a growing one (albeit scarcely yet very fruitful in good works), is now an admitted sign of the times. Commissions and Boards—metropolitan and provincial—are hard at work, doing their best, and stayed only by professional discordance, or limitation of resources. The demand for a second edition of the Rudimentary Treatise on Drainage should be deemed gratifying to the public, as an evidence of the progress of the subject, rather than complimentary to the author as an acknowledgment of his ability in treating it.

Care has been taken to incorporate a record of the most recent results, by which the book is considerably augmented in size, while the indicial headings to the pages may, it is hoped, assist in referring to the facts and details.

DRAINAGE.

DEFINITIONS, AND SYNOPSIS OF THE DIVISIONS IN WHICH THE SUBJECT WILL BE TREATED IN THIS WORK.

1. DRAINAGE is the collecting and conveying away refuse waters, and other matters, from *lands*, *towns*, and *buildings*. It ascertains the means and methods of accomplishing these purposes in the most complete manner; and, as *water* is the principal agent in all cleansing processes, the means required for insuring its supply are among the necessary provisions of efficient drainage. By simply extending the same means, the supply of water may be made adequate to satisfy all other purposes; and it hence becomes desirable to include among the objects of drainage the entire supply of water for towns and buildings, and for the irrigation of lands. *Sewers* are among the essential means of town drainage, and therefore have to be so considered, and their positions, forms, sizes, and modes of construction duly ascertained. Our subject thus embraces several matters which may be treated separately, but which are properly branches of the art of draining, and cannot be consistently studied and usefully applied without a full appreciation of their several and intimate connections.

2. Beyond the limits of the subject of draining as defined (1), it is also to be extended to the ultimate disposal of the refuse matters which it has first to remove from streets and dwellings: and one of its most important duties is to effect this disposal in such a manner that human health shall not be thereby impaired; and, moreover, that the

matters removed shall be made available to the utmost in promoting the fertility of the land, and effecting all chemical purposes for which they are the best fitted.

3. The synopsis of the several heads under which we propose to arrange our facts, principles, and rules, is the following :—

DRAINAGE.

DIVISION I.—DRAINAGE OF DISTRICTS AND LANDS.
DIVISION II.—DRAINAGE OF TOWNS AND STREETS.
DIVISION III.—DRAINAGE OF BUILDINGS AND DWELLINGS.

DIVISION I.

SECTION I.—Sources of Water.—Natural and Artificial Supply.—Rain, Ocean, Rivers, Streams, Springs, &c.—Seasons, Evaporation, Temperature, &c.—Quantity required.—Nature of Soils and Crops, and position of Districts.—Qualities of Water.—Rain Water, Sea Water, River and other Waters—Four kinds of Impurities.—Modes of Purifying.—Subsidence. — Filtration. — Chemical Process. — Natural Filters.

SECTION II.—Upper and Lower Districts.—River-watered and Sea-coast Districts.—Reclamation of Land.—Modes of Draining, Pumping, &c. — Water-wheels, as applied for Draining and supplying Upland Districts.

SECTION III. — Means of conveying, distributing, and discharging Water.—Drains and Watercourses; Forms, Sizes, and Methods of Construction.—Implements employed.—Shallow and Deep Draining.—Stone, Tile, Earthenware, and Brick Drains, &c.

DIVISION II.

SECTION I.—Classification of Towns according to Position and Extent.—Varieties of Surface Levels and Inclinations.

SECTION II.—Supply of Water.—Public Filters and Reservoirs, &c.

SECTION III. —Width and Direction of Roads and Streets; Substructure and Surface.—Paving and Street Cleansing.

SECTION IV.—Main Sewers; Proportions and Dimensions, Inclinations, Forms, and Construction.—Upper and Lower Connections.—Means of Access and Cleansing.—Adaptation for Street Cleansing, &c.

SECTION V.—Conveyance of Water.—Piping, Aqueducts, Reservoirs. —Pumping Apparatus, Steam Draining and Pumping, &c.

DIVISION III.

SECTION I.—Classification of Buildings.

SECTION II.—Supply of Water Levels.—Constant Service.—Quantity required.—Cisterns.—Reservoirs.—Filters, Valves and Apparatus.—Piping, &c., &c.

SECTION III.—Varieties of Manufactures, and best available Methods of Draining.—Arrangement of Separate and Collective Drains.—Proportion of Area of Drain to Cubic Contents of Dwelling-Houses.—Fall of Drains.—Mode of Construction.—Connection with Main or Collateral Sewers. —Means of Access, &c., &c.

SECTION IV.—Water-Closets; Arrangement and Construction.—Adaptation to various circumstances.—Combined Arrangements for efficient House Drainage.—Miscellaneous Apparatus and Contrivances.

GENERAL SUMMARY AND CONCLUSION.

DIVISION I.

DRAINAGE OF DISTRICTS AND LANDS

SECTION I.

Sources of Water.—Natural and Artificial Supply.—Rain, Ocean, Rivers, Streams, Springs, &c.—Seasons, Evaporation, Temperature, &c.—Quantity required.—Nature of Soils and Crops, and position of Districts.—Qualities of Water.—Rain Water, Sea Water, River and other Waters.—Four Kinds of Impurities.—Modes of Purifying.—Subsidence.—Filtration.—Chemical Process.—Natural Filters.

1. Water is indispensable to animal existence and health. The means of obtaining, treating, and economizing this vital liquid are therefore among the most important objects of human art. The several sources, primary and secondary, of water, are the ocean, rivers, streams, lakes, subterranean collections or springs, and rain. Some or other of these sources are at our command, to some extent, in every region of the habitable globe. The applicability of the first-named four sources is limited by the geographical position of the district; the latter two of them are obtainable nearly everywhere. The ceaseless cycle of operations by which the waters on the earth and of the ocean mingle with the atmosphere by the medium of evaporation, and, descending in the forms of rain and dew, sprinkle the surface, and again unite through streams and rivers in their common reservoir, is one of the most beautiful and interesting illustrations of the compensating principle of the economy of Providence.

2. In adopting the terms *natural* and *artificial* supply as contradistinguished, it may appear that the former should apply commonly to all the sources enumerated, except the subterranean. We would, however, limit the term *natural* supply to rain and dew, since all the other sources require more or less of artificial means before they are generally available for the purposes of man. Thus the water of the ocean must undergo chemical change or distillation,

and that of rivers requires artificial channels and conduits for its distribution. These, therefore. like the subterranean, for which wells and borings are necessary, have to be classed among the artificial sources of water.

3. The quantity of evaporation from land-surface is evidently more limited than that from water-surface, the one depending upon the retentive power of the super-soil, and the facility for capillary action, while the other arises from a source comparatively inexhaustible. The rate of the process is controlled by temperature, and accelerated in proportion to the heat acting upon the surface; the temperature being affected by the elevation, and reduced in proportion as the elevation increases. The joint result of these conditions is, that proximity to the sea, the river, or the lake, promotes the natural supply of water in the form of rain. The geography of the district, therefore, affects the facility or difficulty of the natural supply.

But another consideration also affects this supply, viz., the superficial features of the district. Thus a mountainous character, augmenting the surface exposed to oblique showers, increases the quantity received on the one side, and diminishes that on the other; and the sides of a valley, in like manner, receive more or less than the quantity due to a level district.

4. The natural supply is, moreover, modified in effect by the structure of the surface on which it falls. Thus, upon a rock-surface (such as that presented by mountains), which resists percolation, the rain collects in masses, floods itself through a fissure, or wears a channel along the line of the most pervious formation, and reaches the lower plains in the formidable rush of a mountain torrent. And as, generally, the effect of the natural supply of water is in proportion to the comparative impermeability of the soil, it follows, that the value of this supply in any district is further conditional on the structural character of the adjacent districts. Thus, from a higher impermeable district it will receive, and to a lower more permeable district it will give.

Natural supply is hence, in effect, determined by the geographical situation, the superficial character, and the geological structure of a district, modified also by the structure of the surrounding district.

5. The quantity of rain that falls annually at several places, has been observed, and recorded as follows:—

In England, the mean annual depth of the eight years 1836 to 1843, both included, was 26·61 inches, having varied between the extremes of 21·1 and 32·1 inches. The average annual fall at some other places has been recorded as follows:—

South Carolina	50 inches.
Bombay (mean of 10 years) . .	78
Brazil (in 1821)	280
Cumana	8

Humboldt has assigned the fall of rain to vary with the latitude, being greatest at the equator, and diminishing towards the poles in the following ratio: viz., 96 inches annually in the equatorial zone, 80 inches to latitude 20°, 29 inches to latitude 45°, and 17 inches to latitude 60°.

6. The quantity of rain thus varying, with some reference to the latitude, also to the position of the district in relation to the sea, and varying also from one year to another, is further affected by the season. Thus, the mean fall per month on an average of eight years in some districts of England has been recorded as fluctuating from 1·617 inch in March to 3·837 inches in November; the fall in each month being as follows:—

TABLE I.

	Inches.
January	1·847
February	1·971
March	1·617
April	1·456
Carried forward......	6·891

	Inches.
Brought forward......	6·891
May	1·856
June	2·213
July	2·287
August	2·427
September	2·639
October	2·823
November	3·837
December	1·641
	26·614

7. This monthly quantity, being the mean of eight years, does not by any means indicate the monthly proportion for any one year, the variation being as great between the same months of different years, as it is from one year to another, or indeed from one latitude to another. Thus, during the eight years over which these observations extended, the quantity of rain falling in each month was as follows:—

TABLE II.

MONTH.	YEARS.							
	1836.	1837.	1838.	1839.	1840.	1841.	1842.	1843.
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
January	2·40	2·40	0·31	1·40	3·95	1·50	1·36	1·46
February	2·04	2·85	2·65	1·45	1·32	1·02	2·02	2·42
March	3·65	0·75	1·55	1·92	0·34	1·65	2·20	0·88
April	2·57	1·32	1·35	1·65	0·34	1·85	0·47	2·10
May	0·70	0·94	0·84	1·22	2·62	1·68	1·85	5·00
June	1·80	1·86	2·85	3·31	1·33	3·00	2·00	1·56
July	2·29	1·30	2·35	4·36	1·68	2·80	1·93	2·09
August	2·24	3·00	0·95	3·65	1·90	3·62	1·40	2·66
September	2·60	1·38	2·47	3·22	2·31	4·00	4·50	0·63
October....	4·55	1·55	2·68	1·68	1·50	4·40	1·41	4·82
November.........	3·95	2·05	3·55	4·40	4·25	4·23	5·77	2·45
December	2·21	1·70	1·58	3·02	0·40	2·30	1·52	0·40
Quantity in each year ...	31·00	21·10	23·13	31·28	21·44	32·10	26·43	26·47

The greatest and least quantity falling in each month during the period is thus stated:—

TABLE III.

Month.	Maximum.	Minimum.	Difference.
	Inches.	Inches.	Inches.
January	3·95	0·31	3·64
February	2·85	1·02	1·83
March	3 65	0·34	3·31
April	2·57	0·34	2·23
May	5·00	0·70	4·30
June	3·31	1·33	1·98
July	4·36	1·30	3 06
August	3·65	0·95	2·70
September	4·50	0·63	3·87
October	4·82	1·41	3·41
November	5·77	2·05	3·72
December	3·02	0·40	2·62

The third column shows the difference between the greatest and least fall in each month during the eight years, and thus represents the relative variableness of each month's rain. It thus appears that the fluctuation is least in February, and greatest in May.

8. As evidence of the great difference of quantity of rain which falls in similar latitudes, we may quote the following observations referring to the upland districts about Manchester, which we have compiled from Tables given by Mr. Homersham in his "Report on the Supply of Surplus Water to Manchester, &c."* These observations were made at eight stations during the four years 1844, 1845, 1846, and 1847; and at five other stations during the year 1847 only. The first column gives the name of the station at which the observations were made; the second shows its elevation above the mean level of the sea; the next five columns contain the depth of the rain in inches and decimal parts for each year, and mean depth of the four years; and the last column gives the names of the observers.

* Weale. 1848.

TABLE IV.

Station.	Elevation in feet.	Depth of rain in inches during the years 1844.	1845.	1846.	1847.	Mean.	Observers.
Fairfield	220	26·35	38·90	30·20	40·75	34·05	Mr. J. Meadows.
Bolton	320	34·63	48·11	40·82	52·32	43·97	,, H. H. Watson.
Newton	350	..	..	..	34·69	34·69	,, J. Meadows.
Rochdale	500	34·41	51·64	42·04	51·72	47·45	,, J. Ecroyd.
Marple	531	29·40	38·80	32·35	43·70	36·06	,, J. Meadows.
Todd Brook Reservoir	620	..	..	..	38 39	38·39	,, Ditto.
Comb's Reservoir	720	42·70	51·10	38·10	51·30	45·80	,, Ditto.
Belmont, Sharples	820	50 00	55 00	49·80	61·40	54·05	,, J. Magnall.
Woodhead Tunnel	1000	..	..	..	33·12	33·12	,, J. Meadows.
Chapel-en-le-Frith	1121	33·00	43·80	38·80	44·00	49·90	,, Ditto.
Whiteholme Reservoir, Blackstone edge	1500	24·80	39·80	37·10	35·70	34·35	,, R. Mathews.
Brinks	1500	..	..	..	29·50	29·50	,, J. Meadows.
Comb's Ridge	1670	..	..	..	35·85	35·85	,, Ditto.
Mean of each of the four years at eight stations		34·41	45·89	38·65	47·61		
Mean of the one year at thirteen stations		..	..	..	42·49		

Among the many observations made upon this subject, it must, however, be admitted that we have not yet the means of instituting any very satisfactory comparison. To do this we require careful observations carried on for a long series of years, at stations selected for the purpose, and with apparatus of the same construction.

9. Any attempt to describe the several fluctuations which are observed in the quantity of rain falling, or to explain the causes of these fluctuations, beyond the few leading circumstances we have noticed, would involve an elementary inquiry into the phenomena of rain far exceeding the limits of these pages. But we may quote a few words from the celebrated Dalton, which will be fully suggestive to the studious mind in this interesting department of meteorological science. "The cause of rain, therefore, is now, I consider, no longer an object of doubt. If two masses of air of unequal temperatures, by the ordinary currents of the winds, are intermixed, when saturated with vapour, a precipitation ensues. If the masses are under saturation, then

less precipitation takes place, or none at all, according to the degree. Also, the warmer the air, the greater is the quantity of vapour precipitated in like circumstances." "Hence the reason why rains are heavier in summer than in winter, and in warm countries than in cold." *

10. The depth of rain which falls is ascertained by receiving it in a vessel of some form with a gauge connected, in which the depth may be accurately measured; but no instrument of the kind yet devised can be considered as entirely satisfactory in its action, or as giving results which will allow estimates of perfect correctness to be thence formed. The rain-gauge used by Dr. Dalton for a series of experiments extending from 1795 to 1819, or later, consisted of "a funnel of 10 inches diameter, and the top surrounded by a perpendicular rim of 3 inches high, to prevent any loss by the spray; it was fixed in a proper frame with a bottle for the water, and stood above 2 feet above ground." Dr. Garnett, in 1795, suggested the addition to this simple form of gauge, of a cup inverted over the mouth of the bottle, and adapted to receive closely the neck of the funnel, so as to prevent the passage into the bottle of any water striking against or condensing upon the outer surface of the funnel. Gauges which have been subsequently used for many observations consist of a hollow cylinder of copper or other metal, 7 or 8 inches in diameter, and from 30 to 40 inches in length, with a perforated funnel or colander of the same diameter, fitted within the cylinder a few inches below the top. A float is placed within the cylinder and fitted with a staff which passes upward through a hole in the funnel, and, standing above the cylinder, serves to indicate the depth of rain accumulated within the cylinder. Experiments, with an apparatus adapted for the purpose, and called a *staff gauge*, have shown that the prolongation

* Memoirs of the Literary and Philosophical Society of Manchester; vol. iii., second series, 1819, p. 507. Several valuable papers, with detailed observations made during long series of years, by Dr. Dalton and others, are to be found in these Memoirs.

of the staff above the cylinder collects a great quantity of rain, and thus shows a greater depth than is due to the surface of the cylinder. This might be obviated by using a cylinder of glass inclosed in a suitable case, or a metal cylinder fitted with a glass panel, for observing the position of the float inside, and dispensing with the staff altogether. The apparatus must be partly sunk in the ground within a strong case, to prevent injury, and capable of being readily taken out when required.

11. The effectiveness of rain for all purposes of water-supply and drainage can be estimated only after determining the deduction due to the process of *evaporation*, by which the larger part of it is raised from the surface on which it has fallen, and, in the form of vapour, mingles with the atmosphere, to be again precipitated upon the earth and ocean. The proportion evaporated appears to be mainly dependent upon the temperature, heat promoting the process, and cold retarding it. The highest, lowest, and mean temperature in each month have been observed to be as follows:—

TABLE V.

Month.	Thermometer.		
	Highest.	Lowest.	Mean.
January	52°·0	11°·0	36°·1
February	53·0	21·0	38·0
March	66·0	24·0	43·9
April	74·0	29·0	49·9
May	70·0	33·0	54·0
June	90·0	37·0	58·7
July	76·0	42·0	61·0
August	82·0	41·0	61·6
September	76·0	36·0	57·8
October	63·0	27·0	48·9
November	62·0	23·0	42·9
December	55·0	17·0	39·3

And, accordingly, we find the proportion of rain evaporated corresponds with the temperature recorded thus:—being the mean evaporation of each month during the eight years 1836 to 1843, and stated at per cent. upon the quantity of rain.

TABLE VI.

Month.	Evaporation per cent.	Remainder per cent.
January	29·3	70·7
February	21·6	78·4
March	33·4	66·6
April	79·0	21·0
May	94·2	5·8
June	98·3	1·7
July	98 2	1·8
August	98·6	1·4
September	80·1	13·9
October	50·5	49·5
November	15·1	84·9
December	00·0	100·0
Mean	57·6	42 4

The remainder stated in the second column shows the per centage upon the total quantity falling which is available for human purposes.

12. Besides the main condition of temperature, other minor circumstances affect the proportion of rain which passes from the surface in the state of vapour, and have to be considered in forming an estimate, from these records, of the available quantity of rain-water in any district. These minor conditions are chiefly the *structure* and the *state* of the supersoil and of the subsoil. Thus, if the structure be of an impermeable character, the water will lie upon the surface, while evaporation takes up more than its average quantity, being hindered only by the provision which may exist for passing the rain immediately to a more porous surface. On the other hand, a soil of excessive permeability will imbibe the water rapidly, and thus reduce the amount of evaporation. The *state* of the soil affected

by the frequency and extent of the showers will, moreover, determine in some degree the relative quantities of rain-water evaporated and retained. Thus, if the soil has acquired excessive hardness from long drought, or become super-saturated by excessive rain, evaporation will proceed more rapidly than percolation, and the effect of the fall be similarly diminished.

13. The average quantity remaining to filter through the soil, or to be made use of for the purposes of man, may be computed from the following Table, No. VII., which shows the average monthly fall during the same period of eight years as stated in Table No. I., the quantity evaporated, and the quantity remaining, in inches.

TABLE VII.

Month.	Rain.		
	Total falling.	Evaporated.	Remaining.
	Inches.	Inches.	Inches.
January	1·847	0·540	1·307
February	1·971	0·424	1·547
March	1·617	0·540	1·077
April	1·456	1·150	0·306
May	1·856	1·748	0·108
June	2 213	2·174	0·039
July	2·287	2·245	0·024
August	2·427	2·391	0·036
September	2·639	2·270	0·369
October	2·823	1·423	1·400
November	3·837	0·579	3·258
December	1·641	0·164	1·805
	26·614	15·320	11·294

14. Of the quantity remaining and available, 11·294 inches per annum, it is desirable to notice the proportion due to the season. Thus, during the months of January, February, March, and October, the quantity is nearly uniform, varying only between 1·077 and 1·547. In the

month of December it rises to 1·805, while in November it averages a depth of 3·258 inches. During the six consecutive months of April, May, June, July, August, and September, the quantity remaining is comparatively small, being always less than half an inch in depth. The following Table, No. VIII., shows the monthly quantity in cubic feet and weight of water remaining on each superficial acre, as computed from the preceding Tables.

TABLE VIII.

Month.	Rain-water permanently deposited per acre.	
	Quantity in cubic feet.	Weight in tons.
January	4744	132·
February	5616	156·
March	3916	109·
April	1111	39·
May	392	11·
June	142	4·
July	87	2·42
August	131	3·61
September	1339	37·
October	5082	141·
November	11826	328·
December	6552	182·
	40932	1145·03

15. The following observations on evaporation and filtration,* for which we are indebted to the patient and carefully-conducted experiments of Mr. Charles Charnock, of Holmfield House, near Ferry-Bridge (one of the Vice-Presidents of the Meteorological Society of London), present some valuable facts for consideration.

* Quoted by J. H. Charnock, Esq., Assistant Commissioner under the Drainage Acts, in a paper "On Suiting the Depth of Drainage to the Circumstances of the Soil," given in the Journal of the Royal Agricultural Society, vol. x. pt. ii. pp. 515 to 518.

TABLE IX.—AN ACCOUNT of OBSERVATIONS made, through a series of Five Years, at Holmfield House, near Ferrybridge, in the County of York, by Charles Charnock, Esq., with a view to determine the amount of Evaporation and Filtration under the several circumstances on the Magnesian Limestone Soil.

EXPLANATION.—Column 1.—Shows the Depth of Rain fallen, as registered by the ordinary Rain-Gauge.

Column 2.—Is the Amount of Evaporation from a Surface of Water fully exposed to both Sun and Wind.

Column 3.—Is the Evaporation from Water, shaded from the Sun, but exposed to the Wind.

Column 4.—Is the Evaporation from what represented drained or dry land.

Column 5.—Is the Evaporation from the same when saturated.

Column 6.—Is the Amount of Water which filtered through the soil.

Into a leaden vessel, of a foot square and three feet deep, was put two feet of gravel and calcareous sand, so as to represent the substratum of the farm, and the remainder filled up, to within an inch of the top, with an average quality of soil. At the bottom a pipe was inserted, which conveyed all the water which was filtered through into a bottle, which was regularly emptied and registered. The vessel was inserted in the ground to within an inch of the surface, keeping the level of the soil, inside and outside, alike, with an inch of the vessel above, to prevent any communication of water from without. The soil was kept free from weeds, and occasionally stirred, that it might not be more than ordinarily compact.

MONTHS.	1842.						1843.					
	Rain.	Evaporation.				Filtration.	Rain.	Evaporation.				Filtration.
	1	2	3	4	5	6	1	2	3	4	5	6
		From Water.		From Soil.				From Water.		From Soil.		
	On the Surface.	Exposed to both Sun and Wind.	Shaded from Sun, but exposed to Wind.	When Drained.	When Saturated.	Through the Soil from the Drain 3 ft. deep.	On the Surface.	Exposed to both Sun and Wind.	Shaded from Sun, but exposed to Wind.	When Drained.	When Saturated.	Through the Soil from the Drain 3 ft. deep.
January....	2·70	1·69	1·13	1·66	1·59	1·04	1·48	2·57	1·71	0·69	1·87	0·79
February ..	0·76	1·23	0·81	0·68	1·04	0·08	3·25	2·65	1·10	2·29	2·78	0·96
March	3·48	1·92	1·28	2·40	2·52	1·08	0·95	3·05	2·03	0·72	2·43	0·23
April	1·51	2·98	1·99	1·11	2·31	0·40	2·19	3·22	2·05	1·84	2·39	0·25
May	2·98	4·14	2·76	2·89	3·82	0·09	2·81	2·91	1·94	2·47	2·65	0·34
June	1·94	4·18	2·79	1·94	4·27	—	2·31	5·12	3·41	2·10	4·86	0·21
July	3·74	4·16	2·73	3·26	3·89	0·48	2·70	3·76	2·50	2·55	3·49	0·15
August	1·49	3·36	2·24	1·37	2·39	0·12	3·99	3·71	2·57	3·77	6·74	0·22
September .	2·44	2·30	1·74	2·24	2·88	0·20	1·47	2·06	1·34	0·90	2·18	0·17
October....	1·12	2·00	1·37	0·92	1·90	0·20	1·10	1·80	1·20	0·82	1·93	0·28
November .	3·19	2·26	1·50	2·49	1·83	0·70	2·30	1·64	1·09	1·69	1·48	0·67
December..	0·76	3·00	2·14	0·60	1·49	0·16	0·28	1·68	1·78	0·27	1·39	0·01
Totals..	26·11	33·61	22·48	21·56	30·02	4·55	24·49	34·17	22·72	20·11	31·19	4·28

TABLE IX.—*continued.*

1844.

Months.	Rain. 1 On the Surface.	Evaporation. From Water. 2 Exposed to both Sun and Wind.	3 Shaded from Sun, but exposed to Wind.	From Soil. 4 When Drained.	5 When Saturated.	Filtration. 6 Through the Soil from the Drain 3 ft. deep.
January	1·31	1·61	1·08	0·85	1·50	0·46
February	2·22	1·31	0·88	1·66	1·11	0·36
March	2·27	2·13	1·42	1·58	1·50	0·69
April	0·27	3·83	2·55	0·27	3·42	—
May	0·42	5·77	3 85	0·42	4·86	—
June	1·24	5·31	3·58	1·20	4·95	0·04
July	2·76	4·17	2·78	2·43	4·28	0·33
August	2·85	4·70	3·14	2·44	4·63	0·41
September	1·92	4·91	3·28	1·62	3·96	0·30
October	1·41	2·79	1·86	1·17	2·93	0·24
November	1·98	2·84	1·80	1·47	2 78	0·51
December	0·35	0·79	0·53	0·29	0·93	0·06
Totals	19·00	40·16	26·75	15·40	37·85	3·60

1845.

Months.	Rain. 1 On the Surface.	Evaporation. From Water. 2 Exposed to both Sun and Wind.	3 Shaded from Sun, but exposed to Wind.	From Soil. 4 When Drained.	5 When Saturated.	Filtration. 6 Through the Soil from the Drain 3 ft. deep.
January	1·74	1·53	1 02	1·28	1·49	0 46
February	0·73	0·71	0·47	0·43	0·94	0·30
March	1·88	2·91	1·94	1·33	2·89	0·55
April	1·54	4·79	3·19	1·05	4·06	0·39
May	2·24	2 84	1 99	1·97	3·26	0·27
June	3·18	3·10	2·06	2·93	2·98	0·25
July	3·49	2·86	1·89	8·30	2·79	0·19
August	4·61	2·56	1·70	4·24	2·43	0·37
September	1·36	2·79	1·86	0·95	2·29	0·41
October	3·36	2·77	1·84	2·69	2·82	0·67
November	1·01	2·13	1·41	0 73	2·20	0·28
December	3·04	3·57	2·38	2·36	2·87	0·68
Totals	28·18	32·56	21·75	23·26	31·09	4·92

1846.

Months.	Rain. 1 On the Surface.	Evaporation. From Water. 2 Exposed to both Sun and Wind.	3 Shaded from Sun, but exposed to Wind.	From Soil. 4 When Drained.	5 When Saturated.	Filtration. 6 Through the Soil from the Drain 3 ft. deep.
January	2·18	2·07	1·58	1·22	1·94	0·96
February	0 47	2·59	1·69	0·44	2·09	0·03
March	0·93	2·56	1·55	0·86	2·16	0 07
April	5 97	1·91	1·27	2·98	1·49	2·99
May	0·82	4·52	3·02	0·73	3·89	0·09
June	1·65	4·88	3·25	1·58	4·73	0·07
July	2·90	4·44	2·96	2·74	4·39	0·16
August	2·65	3·08	2·05	2·46	3 28	0·19
September	1·07	2·99	1·99	1·00	3·14	0·07
October	4·09	2·23	1·49	2·40	2·76	1·69
November	1·15	1·63	1·09	0·88	1·74	0·17
December	1·36	1·79	1·10	1·09	1·67	0·27
Totals	25·24	34·69	23·04	18·38	33·28	6·76

In these experiments, the evaporation from *saturated* soil was determined thus:—"A leaden vessel of 13 inches deep, and a foot square, was filled to within an inch of the top with soil, and placed in the ground, in the same manner as the previous vessel, with a pipe level with the surface of the soil to carry off the excess of top-water into a receiver. The same quantity of water was then daily supplied to this soil as the evaporating dish of column 2 showed was evaporated. The soil was stirred as in the former case, and thus represented wet and undrained land."

"In the first place, it is observable how much greater is the amount of evaporation from water than from land, and how near, as shown by columns 2 and 5 (Table IX., pp. 15, 16), the evaporation from wet land is to that from water itself—hence the wetter the land the greater the evaporation, and, as the well-known consequence, the greater its excess of coldness. We have a familiar illustration of nature's process in this particular, in the method often adopted to cool our wine on a hot summer's day, by wrapping a wet napkin round the bottle and exposing it to the full sun; as the moisture from the napkin is evaporated, the temperature of the wine declines to almost freezing point. The school-boy's experiment of producing ice before a fire, by incasing the vessel in wet flannel and adding a portion of salt to the water, is a similar example, with this additional lesson to the farmer—that to apply certain limes to wet land is only increasing the evil.

"You will then, in the second place, notice how much less the evaporation is in the shade than in the sun, and consequently that wet land must be the warmest when there is the least sun. From which cause, no doubt, arises that too vigorous growth of young wheat, so often observable on such land in the winter and spring months, which never fails to produce serious injury to the crop in all its subsequent stages. And thirdly, you will remark how comparatively small a proportion of the rain which falls is shown to be carried off by filtration. Taking the average

of the five years' experiments, it will be seen that only 4·82 inches out of 24·6 inches of rain passed through the land to the depth of three feet. We might, therefore, be led at the first glance to infer that land in general stands less in need of drainage, or may be drained by a less perfect system, than is supposed to be requisite, did not daily experience oppose such a conclusion. We must, therefore, endeavour to reconcile this seeming incongruity, and deduce at the same time, from the facts disclosed, such data as may guide us in determining the essential requisites to ensure completeness of effect in drainage.

"Now, although there can be no reason to question the accuracy of the experiments on filtration made by Mr. Dickinson, and recorded in the Journal of the Royal Agricultural Society of England, Vol. V., Part I., yet there is a very considerable difference in the aggregate result, as shown by them and the account before us. 'The first important fact disclosed,' says the commentator, page 148, 'is, that of the whole annual rain, about $42\frac{1}{2}$ per cent., or $11\frac{3}{10}$ inches out of $26\frac{6}{10}$,* have filtered through the soil:' whereas in the Holmfield House experiments there is only shown, as we have already said, 4·82 inches out of 24·6, or about $5\frac{1}{10}$ per cent. against $42\frac{1}{2}$ per cent. This is certainly a very great and somewhat irreconcileable difference in the result of two experiments made professedly to ascertain the same fact. Now, on referring to the 'Memoirs of the Literary and Philosophical Society of Manchester,' Vol. V., Part II., you will find a paper on rain, evaporation, &c., from the pen of the celebrated Dr. John Dalton (the father of the science of Meteorology), wherein he explains a series of experiments made by himself and his friend, Mr. Thomas Hoyle, jun., to ascertain the amount of evaporation and filtration, and giving the following Table of results:†—

"'Having got a cylindrical vessel of tinned iron,' says the Doctor, 'ten inches in diameter and three feet deep, there were inserted into it two pipes, turned downwards,

* See Table VII. p. 13. † See Table X. p. 19.

TABLE X.

Months.	Water through the Two Pipes.			Mean.	Mean Rain.	Mean Evaporation.
	1796.	1797.	1798.			
January	1·897	·680	1·774	1·450	2·458	1·008
February	1·778	·918	1·122	1·273	1·801	·528
March	·431	·070	·335	·279	·902	·623
April	·220	·295	·180	·232	1·717	1·485
May	2·027	2·443	·010	1·493	4·177	2·684
June	·171	·726	...	·299	2·483	2·184
July	·153	·025	...	·059	4·154	4·095
August	...	...	·504	·168	3·554	3·386
September	...	·976	...	·325	3·279	2·954
October	...	·680	...	·227	2·899	2·672
November	...	1·044	1·594	·879	2·934	2·055
December	·200	3·077	1·878	1·718	3·202	1·484
	6·877	10·934	7·379	8·402	33·560	25·158
Rain	30·629	38·791	31·259			
Evaporation	23·725	27·857	23 862			

for the water to run off into bottles: the one pipe was near the bottom of the vessel, the other was an inch from the top. The vessel was filled up, for a few inches, with gravel and sand, and all the rest with good fresh soil. Things being thus circumstanced, a regular register has been kept of the quantity of rain-water that ran off from the surface of the earth through the upper pipe (whilst that took place), and also of the quantity of that which sank down through the three feet of earth, and ran out through the lower pipe. A rain-gauge of the same diameter was kept close by, to find the quantity of rain for any corresponding time.'

"You will notice that the general result of these experiments accords pretty nearly with that of the Holmfield account; and yet it may be readily conceived that circumstances of situation and stratification may often occasion as wide a difference in the amount of filtration as is shown between Mr. Dickinson's and Mr. Charnock's observations.

"On an examination of the *details* registered in the account before us, it will be evident that the amount of filtration is not exclusively dependent on the fall of rain; but that a variety of other causes combine to affect its proportion. For instance, in March, April, May, June, and July, of 1842, the fall of rain was 13·65 inches, and the filtration for the same period was only 2·05 inches; whilst in April, 1846, there was 5·97 of rain and 2·99 of filtration. Similar instances are also noticeable in Mr. Dickinson's details. From March to October, inclusive, of 1840, a fall of 11·52 inches of rain is recorded, without any filtration; but in November, 1842, the rain was 5·77, with 5 inches of filtration. Dr. Dalton's table also shows the same variations. The lesson, therefore, derivable from these experiments, so far as regards filtration by drains, is one rather of a speculative than of a definite character; for, although we are assured filtration must be secured, we are left with a large and varying margin as to the proportion. We must not, however, overlook the fact, that all the registered details show occasionally an amount of filtration nearly equal to the rain that falls, and, therefore, in determining the size of pipe to be used, the ready exit of this *maximum* quantity must be provided for."

16. The precise *quantity* of water *required* for the agricultural purposes of any district depends upon the nature of the soil and the crops, and the position of the district in relation to the surrounding country. Thus, if a permeable soil occupy an elevated site, the water deposited upon it will pass rapidly, and perhaps before serving for the germination or the nutriment of the plant. If, on the other hand, as is the far more common case in this country, the soil be of a retentive character, and the site low in relation to other districts, the water will be kept while the soil becomes saturated to so great an extent that the processes of vegetable germination and growth are greatly impeded. The soil exists in one of three conditions; 1st, in the form of clay ,being a dense mass consisting of finely comminuted particles, but all of a highly tenacious kind; in a state of

slight moisture it becomes a clammy paste, and is never found so utterly devoid of moisture that its constituent particles are separable: it affords no passages for water, receiving it with difficulty, and retaining it in the same way. 2nd, in the form of sand or gravel, the particles of which are seldom or never united, and the soil is therefore full of passages or canals for water. Soil of this kind has no power either to oppose the admission or effect the retention of water poured upon it. And 3rd, existing in the form of a mixture of the aluminous, silicious, and calcareous elements, in endless variety of proportions, found as *clods*, and in this state affording two classes of passages for the ingress and permeation of water, viz., those remaining between the particles which are congelated in each clod, and those formed by the spaces between the clods. The former are sometimes called *pores*, and the latter *canals*. The power of admitting and retaining or discharging water exerted by these mixed soils, will exist in an endless variety of degrees, according to the mechanical formation of the constituent particles and clods. The state of soil which is most favourable for the germination and development of the plant is that of *moistness*, capable of being readily crumbled by the hand, and equally removed from the adhesive extreme of *mud* and the volatile one of *dust*. In this condition it will be found that the *pores* are filled with water, but the *canals* are not—these latter serving as passages for the air, which is one of the feeders of vegetable life; and we can, therefore, readily understand that, when water exists in such quantity that the soil is saturated with it, and all the pores or canals filled, its condition is unhealthy for the growth and development of plants.

The following extract, from an admirable lecture on Agricultural Science, by Dr. Madden, quoted by the General Board of Health in their "Minutes of Information," although of considerable length, claims a space here, for the valuable information it conveys on the fitness of soil for promoting vegetable germination.

"The first thing which occurs after the sowing of the

seed is, of course, *germination;* and before we examine how this process may be influenced by the condition of the soil, we must necessarily obtain some correct idea of the process itself. The most careful examination has proved that the process of germination consists essentially of various chemical changes, which require for their development the presence of air, moisture, and a certain degree of warmth. Now it is obviously unnecessary for our present purpose that we should have the least idea of the nature of these processes: all we require to do, is to ascertain the conditions under which they take place; having detected these, we know at once what is required to make a seed grow. These we have seen, are air, moisture, and a certain degree c warmth; and it consequently results, that wherever a seed is placed in these circumstances, germination will take place. Viewing matters in this light, it appears that soil does not act *chemically* in the process of germination; that its sole action is confined to its being the vehicle by means of which a supply of air and moisture and warmth can be continually kept up. With this simple statement in view, we are quite prepared to consider the various conditions of soil, for the purpose of determining how far these will influence the future prospects of the crop, and we shall accordingly at once proceed to examine carefully into the *mechanical relations of soil.*

17. Soil, examined mechanically, is found to consist entirely of particles of all shapes and sizes, from stones and pebbles down to the finest powder; and on account of their extreme irregularity of shape, they cannot lie so close to one another as to prevent there being passages between them, owing to which circumstance soil in the mass is always more or less *porous.* If, however, we proceed to examine one of the smallest particles of which soil is made up, we shall find that even this is not always solid, but is much more frequently porous, like soil in the mass. A considerable proportion of this finely-divided part of soil, the *impalpable matter* as it is generally called, is found, by the aid of the microscope, to consist of *broken-down vegetable tissue,*

so that when a small portion of the finest dust from a garden or field is placed under the microscope, we have exhibited to us particles of every variety of shape and structure, of which a certain part is evidently of vegetable origin.

18. On examining a *perfectly-dry* soil we perceive that there are two distinct classes of pores: 1st, the large ones, which exist *between* the particles of soil; and 2nd, the very minute ones, which occur in the particles themselves; and whereas all the larger pores—those between the particles of soil—communicate most freely with each other, so that hey form canals, the small pores, however freely they may pmmunicate with one another in the interior of the particle h which they occur, have no direct connection with the pores of the surrounding particles. Let us now, therefore, trace the effect of this arrangement. If the soil is *perfectly dry*, the canals communicating freely at the surface with the surrounding atmosphere, the whole of these canals and pores will, of course, be filled with air. If, in this condition, a seed be placed in the soil, you at once perceive that it is freely supplied with air, *but there is no moisture;* therefore, when soil is *perfectly dry*, a seed cannot grow.

19. Let us turn our attention now to that state of the soil in which water has taken the place of air, or, in other words, the soil is *very wet.* If we observe our seed now, we find it abundantly supplied with water, but *no air.* Here again, therefore, germination cannot take place. It may be well to state here, that this can never occur *exactly* in nature, because water having the power of dissolving air to a certain extent, the seed is in fact supplied with a *certain* amount of this necessary substance; and, owing to this, germination does take place, although by no means under such advantageous circumstances as it would were the soil in a better condition.

20. We pass on now to a different state of matters. Let us suppose the canals are open and freely supplied with air, while the pores are filled with water. While the seed now has quite enough of air from the canals, it can never be

without moisture, as every particle of soil which touches it is well supplied with this necessary ingredient. This, then, is the proper condition of soil for germination, and, in fact, for every period of the plant's development; and this condition occurs when soil is *moist* but not *wet*—that is to say, when it has the colour and appearance of being well watered, but when it is still capable of being crumbled to pieces by the hands, without any of its particles adhering together in the familiar form of mud.

21. Let us observe still another condition of soil; in this instance, as far as *water* is concerned, the soil is in its healthy condition—it is moist, but not wet, the pores alone being filled with water. But where are the canals? We see them in a few places, but in by far the greater part of the soil none are to be perceived; this is owing to the particles of soil having adhered together, and thus so far obliterated 'the interstitial canals that they appear only like pores. This is the state of matters in every *clod of earth*; and you will at once perceive, on comparing it with a stone, that it differs from it only in possessing a few pores, which latter, while they may form a reservoir for moisture, can never act as vehicles for the *food* of plants, as the roots are not capable of extending their fibres into the interior of a clod, but are at all times confined to the interstitial canals.

22. With these four conditions before us, let us endeavour to apply them *practically* to ascertain when they occur in our fields, and how those which are injurious may be obviated.

The first of them, we perceive, is a state of too great dryness, *a very rare* condition, in this climate at least; in fact, the only case in which it is likely to occur is in very coarse sands, where the soil, being chiefly made up of pure sand and particles of flinty matter, contains comparatively much fewer pores, and, from the large size of the individual particles, assisted by their irregularity, the canals are wider, the circulation of air freer, and, consequently, the whole is much more easily dried. When this state of matters exists, the best treatment is to leave all the stones which occur on

the surface of the field, as they cast shades, and thereby prevent or retard the evaporation of water.

23. We will not, however, make any further observations on this very rare case, but will rather proceed to a much more frequent, and, in every respect, more important condition of soil: an *excess of water.*

When water is added to perfectly dry soil, it of course, in the first instance, fills the interstitial canals, and from these enters the pores of each particle; and if the supply of water be not too great, the canals speedily become empty, so that the whole of the fluid is taken up by the pores: this, we have already seen, is the *healthy* condition of soil. If, however, the supply of water be too great, as is the case when a spring gains admission into the soil, or when the sinking of the fluid through the canals to a sufficient depth below the surface is prevented, it is clear that these also must get filled with water so soon as the pores have become saturated. This, then, is the condition of *undrained soil.*

24. Not only are the pores filled, but the interstitial canals are likewise full; and the consequence is, that the whole process of the germination and growth of vegetables is materially interfered with. We shall here, therefore, briefly state the injurious effects of an excess of water, for the purpose of impressing more strongly on your minds the necessity of thorough-draining, as the first and most essential step towards the improvement of your soil.

The *first* great effect of an excess of water is, that it produces a corresponding diminution of the amount of air beneath the surface, which air is of the greatest possible consequence in the nutrition of plants; in fact, if entirely excluded, germination could not take place, and the seed sown would, of course, either decay or lie dormant.

Secondly, an excess of water is most hurtful, by reducing considerably the *temperature* of the soil: this I find by careful experiment to be to the extent of $6\frac{1}{2}$ degrees Fahrenheit in summer, which amount is equivalent to an elevation above the level of the sea of 1950 feet. So that,

supposing two fields lying side by side, the one drained, the other undrained, and supposing them both equally well cultivated, there will be nearly as much difference in the amount and value of their respective crops, as if the drained one was situated at the level of the sea, and the other had an elevation as high as the most lofty of the Pentland Hills.* But, besides this, and what is nearly equally bad, the temperature is rendered unnaturally high during winter; whereas it has been proved that one great source of health and vigour in vegetation is the great difference which exists between the temperature of summer and winter, which difference amounts in dry soil to between thirty and forty degrees, while in soil very much injured by an excess of water, the whole range of the thermometer throughout the year will probably not exceed from six to ten degrees.

These are the two chief injuries of an excess of water in soil which affect the soil itself. There are very many others affecting the climate, &c.; but these are not so connected with the subject in hand as to call for an explanation here.

25. Of course all these injurious effects are at once overcome by thorough-draining, the result of which is to establish a direct communication between the interstitial canals and the drains, by which means it follows that no water can remain any length of time in these canals without, by its gravitation, finding its way into the drains.

26. Too much cannot be said in favour of pulverising the soil; even thorough-draining itself will not supersede the necessity of performing this most necessary operation. The whole valuable effects of ploughing, harrowing, grubbing, &c., may be reduced to this: and almost the whole superiority of *garden* over *field* produce is referable to the greater perfection to which this pulverising of the soil can be carried.

* Of course the field of high elevation must be *thoroughly* drained to equal even the *undrained* field at the level of the sea.

The celebrated Jethro Tull has the honour of having first directed the farmer's attention forcibly to this subject; and so deeply impressed was he with its infinite importance, that he believed the use of manure could be entirely superseded were this pulverising carried to a sufficient extent.

The whole success of the drill husbandry is owing, in a great measure, to its enabling you to stir up the soil well during the progress of your crop; which stirring up is of no value beyond its effect in more minutely pulverising the soil, increasing, as far as possible, the size and number of the interstitial canals.

27. Lest any one should suppose that the contents of these interstitial canals must be so minute that their whole amount can be of but little consequence, I may here notice the fact, that in moderately-well pulverised soil they amount to no less than one fourth of the whole bulk of the soil itself: for example, 100 cubic inches of *moist* soil (that is, of soil in which the pores are filled with water while the canals are filled with air) contain no less than 25 cubic inches of air. According to this calculation, in a field pulverised to the depth of 8 inches, a depth perfectly attainable on most soils by careful tillage, every imperial acre will retain beneath its surface no less than 12,545,280 cubic inches of air. A familiar illustration of the space occupied by the spaces between the particles of loosened soil is afforded by the fact that when soil is disturbed it more than fills the space it previously occupied.

28. Taking into calculation the weight of soil, we shall find that with every additional inch which you reduce to powder (by ploughing, for example, 9 inches in place of 8), you call into activity 235 tons of soil, and render it capable of retaining beneath its surface 1,568,160 additional cubic inches of air. And, to take one more element into the calculation, supposing the soil were not properly drained, the sufficient pulverising of an additional inch in depth would increase the escape of water from the surface by upwards of 100 gallons a day.

29. The great purpose of draining being, immediately, the improvement of the land, but, ultimately, the promotion and improvement of vegetable production, the preceding considerations as to the fitness of the soil for germination may be well followed by a brief enumeration of the rules for the application of water to plants, which, as laid down by De Candolle, refer

First, to the *quality* of the water used: that it should be well aërated; the presence of atmospheric air is good, but of carbonic acid gas much better. The next qualities desirable are, that it should contain fertilising matters; the water should be as little muddy as possible; the temperature of the water is of importance, especially for hot-house plants: the water used in hot-houses is allowed to stand for some time before it is employed, in order that it may have the temperature of the place; it is well that other water employed should stand for a time in the sun.

Second, to the *times* of the application:—In the winter time there should be little irrigation, because the plants are then dormant, and water is then superabundant. In spring time water is usually abundant. In summer it is wanting; and at that time the water should be given in the evening.

Third, to the *quantity* of the water to be applied, which should be varied according

a. To the *object* of the culture:—When for leaves, more water should be given than when for flowers; less water should be given when for grains or fruits.

b. To the *depths* of the *roots*:—The application should be more frequent to the plants of which the roots are superficial; less frequent to deeper roots.

c. To the *structure* of the *foliage*:—Those which evaporate much (such as plants with large leaves), more frequently than perennial, or plants with thick leaves.

d. To the *consistence* of the *stalks*, and of the *roots*:—Roots with fleshy fibres do not thrive if too abundantly watered; at the same time they are injured by dryness. Tuberculous or bulbous plants, or plants with fleshy leaves, can bear a

long-continued dryness, and therefore infrequent, yet abundant, waterings suit them well.

e. To the *stage* of vegetation:—It is important to bear in mind that young germinating plants require light and frequent waterings; those that are in the height of growth abundant waterings; and when the fruit or seed is being matured the waterings should be infrequent. Those that have been transplanted require abundant watering.

f. To the *nature of the soil*, according to which these rules must be modified:—The lighter the soil the more frequent and plentiful must be the waterings. If it is a compact and clayey soil less watering will be required.

g. To the *state* of the *atmosphere*:—It will be readily conceived that the watering must be more frequent when the temperature is high, the sky clear, and the air dry, and during drought."

30. The *proper* serving of water for agricultural purposes, similarly with that for domestic and manufacturing uses, requires both adequate supply and discharge. That is, if the natural supply be deficient it becomes the business of the drainer to augment it; if excessive, to reduce it: but, in either or any case, his correlative object is to provide sufficiently for the discharge of the water as rapidly as vegetation has imbibed its nutriment from it, and the supply is replenished. The recognition of this essential principle founded the era of all modern improvements in the Art of Draining. The most skilful tenders of the soil were previously satisfied to drain the *surface* of the land. So long as they were enabled by superficial channels to get rid of the excess of water which appeared above ground, their work seemed to them complete, and the effects of subterranean reservoirs and aluminous sponges, made visible in stunted and unhealthy vegetation, were attributed to any causes rather than the true ones. In our third section, which will show in detail the methods of determining and

forming drains, these causes and the mode of treating them will be explained.

31. The facility or difficulty attending the artificial supply of water from rivers and subterranean sources depends upon the distance of the sources from the districts to be watered, their relative levels, and the geological structure of the soil. The map of the district will exhibit the first of these circumstances, and a corresponding section will show the second; the third may be inferred, with more or less exactness, from the superficial features of the country, but can be ascertained with certainty only by boring through the superincumbent strata until the spring or internal reservoir is arrived at.

32. The water of rivers is not generally available for the supply of the lands of districts of superior level, the expense of applying mechanical power for this purpose being too great to admit of extensive operations. For the supply of towns and buildings, however, this consideration is outweighed by the importance of the object. Pumps worked by water, steam, or other power, are applied to raise the water; and artificial channels, such as aqueducts or pipes, provided for its conveyance, with tanks or reservoirs for containing it, and submitting it to any desired operations of cleansing or purifying. If the district to be supplied lie on a level, near to that of the feeding river, the reservoirs are usually constructed contiguous to it, and receive and cleanse the water before its conveyance through pipes or other conduits. Thus, several of the companies who now supply water to London and its suburbs have reservoirs for these purposes on the banks of the river Thames, whence their supply is derived.

33. For the irrigation and draining of adjacent lands on accessible levels, the waters of rivers are conducted by artificial courses. The system of irrigation adopted in Lombardy is complete for this purpose, and the principle of it is illustrated in figures 1 and 2; *a a* is the feeder to

Fig 1.

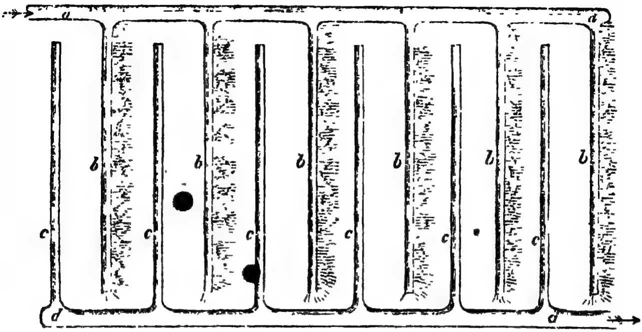


Fig. 2.

Fig. 3.

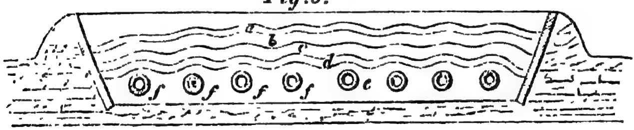
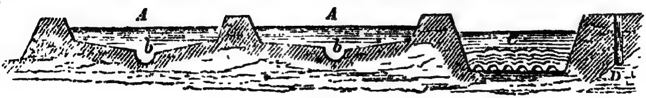


Fig. 4.



b b, the irrigating channels. The water flowing from these spreads itself as a veil over the rectangular sections of land between them, and thence passes into the draining channels *c c*, which are formed at a lower level than the supply channels, and is received in the common drain *d d*, through which it passes, and becomes the means of irrigation and draining to other similar districts in succession. In Lombardy, the width of land between the channels *b* and *c* is usually about 22 feet, and the difference of level between the irrigating and the draining channels about 6 inches. These water-meadows, or *marcite*, are thus irrigated in summer during several hours about once in each week; and from the end of September to the end of March the process proceeds continuously, the water being turned off only while the grass is being cut.

34. Instances of irrigation by *submersion*, by *filtration*, and by *regurgitation*, or subterranean irrigation, are mentioned by Count Manetti, the Superintendent of the Royal Gardens at Monza, near Milan, in these words:—" The irrigation by submersion is, in Lombardy, limited to rice fields. Elsewhere, as, for instance, in Tuscany, it is employed to improve the soil by the deposit of earthy matter from the water, whilst in France and Germany it is employed both for arable lands and meadows, leaving them under water till a scum appears, which indicates that the crust of the soil begins to decay. The irrigation adopted in Lombardy for arable and pasture lands, as well as for meadows, is by filtration, for one could scarcely call submersion that very thin veil of moving water so skilfully spread over the land by our irrigators, who, in this point, are the best agriculturists in the world. The irrigation by regurgitation (more properly subterranean irrigation) is not in use in Lombardy; but in Switzerland, in the neighbourhood of Berne, and especially at Hofwyl, a considerable extent of land is irrigated in this manner with great success. The famous Fellenberg reclaimed the bogs of his Hofwyl estate

by the application of subterraneous drains, so contrived that by stopping their mouths when the surface of the soil is too dry, he compels the water to swell back to the roots of the grass. This mode of irrigation is not only adapted to grassy lands after they have been drained, but to every other description of light soils, especially in hot climates. It was common in Persia long ago."

35. A method of irrigation by water-meadows, similar to that described (par. 33), has been adopted in Wiltshire and the neighbouring counties, the soil being thrown up into beds, the water running along the crown of each bed, and discharging on each side.

36. Another method adopted chiefly, until lately, in Devonshire, is that known by the name *Catch-water Meadow* or *Catch-meadow*. In this arrangement the gutters are drawn along natural slopes, and the water falls from the upper one to that immediately below it, which spreads it anew equally over the surface lower down. This system, originating in an almost mountainous country, has been of late years transferred to land quite as level as any on which the ridge-water meadows were made in Wiltshire.

37. Experiments have been recently made upon the economical effect of substituting an apparatus of pipes or flexible hose for irrigating lands, for the channels and gutters previously described. The chief advantages apparent from the use of pipes either of iron or earthenware, or the flexible hose with lateral openings, as water-carriers or conductors over the water-meadows, have been thus recited: —that the surface now occupied by fixed carriers for water-meadows would be saved; that the flexible hose may be carried across depressions or over undulations of surface, with closed lengths, without the expense of permanent works; that with these tubular carriers less water will suffice, and, therefore, less waste from evaporation; that the apparatus may be at once removed for the adaptation of the land to arable or varied cultivation. The hose may

be carried over hedges, ditches, or even small streams. With a slight covering, it may be carried temporarily over a road, or under it, through a road-drain.

The distribution by the hose and jet admits of various modes of appliance with steam-power, from the heaviest fall of a thunder-shower within the range of the jet, to a shedding in the shape of a mist by a skilful operator, or the shedding in various full streams upon the ground. Horticulturists deem various niceties in watering essential to good production. In the practice of the new distribution on a large scale these points of skill appear to have been little, if at all, attended to; and although crops now deemed extraordinary were got without them, it is probable that, with them, further increase of production will be attained.

38. When the several specified advantages of the pipe-distribution are considered, they appear to the engineering inspectors who have examined the different works, to preponderate greatly, even for common agricultural purposes, over the cheapest methods of distribution by catch-water meadows, and to induce a far higher and more profitable order of cultivation. When, indeed, the question relates to land which is valuable from its contiguity to a town, and to a cultivation yielding 10*l.* or 20*l.* or more per acre, the annual cost of the land occupied by the water-carriers alone exceeds the annual cost of a complete system of iron pipes. Thus, in the newly-formed water-meadows at Edinburgh, the open gutters occupy about one thirty-seventh of the area irrigated, and in many places a greater proportionate space is occupied for the purpose. As the rent of the land is there 20*l.* per acre, the annual value of the space devoted to gutters is 10*s* 9*d.* per acre, or about equal to the average annual working expenses, including interest on capital, of the pipe distribution; and it would be clearly a saving to the owners of those meadows, and of several others, to fill up the gutters, to abandon the practice of distribution by submersion, and to adopt that of pipe dis-

tribution. Besides saving land, filling up the gutters would be removing impediments to the passage of carts, and to numerous other agricultural operations. Where a sufficient fall is obtained for pipe distribution by gravitation, it is cheaper than the common catch-water meadows.

39. The power derivable from the prompt application of plain water to arable cultivation may be said to be unknown to the agriculture of this country, and very little known in that which has heretofore been distinguished as "market garden cultivation;" and it is only imperfectly practised in horticulture. Wheat has, under some circumstances, been watered with great success. In the market-garden cultivation at Naples and Paris, effects are stated to be produced by skilful watering which are unknown in this country. At Naples the water is distributed by regular channels of irrigation. At the market gardens of Paris, it is skilfully distributed by hand labour, by the use of the scoop, at great expense indeed, but for which the extra produce compensates. Some of the more eminent market-gardeners would, however, appreciate the advantages of any appliances for the cheap distribution of water. A quantity of water equal to the fall from a heavy thunder-shower may be distributed by engine power at an expense not exceeding a few pence per acre.

40. The cheap power of distributing water may often be of importance to the agriculturist, to facilitate the working of the land at those times when it is hardened by drought, and when, for ploughing or other work, extra labour, often more than double the ordinary amount, is necessary. On such occasions, labourers wet the ground to facilitate the working with the spade. When water is available, and when the ground may be thoroughly wetted at a trifling expense, the farmer may, by such an application, work with two horses where otherwise four would be required.

41. Districts considerably above river level, or so situated that no water can be conveyed to them from that source, may be artificially supplied from wells, or by making com-

munication with the lower and saturated strata of the soil. Thus, the ridges of land lying above the reach of the Nile were perforated with wells by the ancient Egyptians, as a substitute for the inundation by which the lower banks were fertilized. The Chinese also resort to wells for the purpose of irrigation. In many parts of the East, where the natural supply by rain is deficient, works on a very large scale have been constructed for obtaining water sufficient for irrigating. In Hindostan, Japan, China, Java, Tartary, &c., the supply is, to a great extent, drawn from wells; and in Bengal, Ceylon, the Carnatic, &c., immense tanks have been for ages constructed to contain the valuable liquid.

42. The principal rivers noted for the periodical rising of their waters, are the Nile, the Ganges, the Euphrates, and the Mississippi. Of these, the Nile, which flows from the Jibel Kumri Mountains, begins to rise in June, and by the middle of August attains an elevation of 24 to 28 feet, the inundation flooding the valley of Egypt for a width of 12 miles. The Ganges, flowing from the Himalayas, rises 32 feet from April to August, and creates a flood of 100 miles in width. The Euphrates, from Mount Ararat, rises 12 feet between March and June, and covers the Babylonian plains. The Mississippi, flowing from the Stony Mountains, rises with the melting of the snows from March till June, forming a vast belt of watered surface. At the distance of 1000 miles from the ocean it is said to rise 50 feet, while nearer the sea its rise is considerably reduced by the vast tract which it covers.

43. The periodical rise of river waters gives facilities for their systematic distribution over the higher districts to a most important extent by the construction of canals, of which the ancient Egyptians largely availed themselves. Their canals, branching in various directions, are said to have amounted to 80 in number, and to have extended to 60 or 100 miles each in length. Similarly, the great cavities, called the Lakes of Mœris, Behira, and Mareotis,

are considered to have been reservoirs artificially formed for collecting vast stores of water to be afterwards distributed for irrigation.

44. Among the means of artificial supply, the construction of wells has always been resorted to as a certain method of obtaining water in cases where no other was practicable. Failing rain and rivers, subterranean sources have, from the earliest times, been sought for, the formation of wells being one of the most ancient engineering expedients. The primitive wells of Greece are described as being surmounted with massive marble cylinders; those of Thrace consisted of arched excavations in the sides of rocks, where the water was directly obtainable from springs; the springs of Turkey were converted into fountains, and "the castle of Cairo contains a curious well, sunk in the rock to the depth of 280 feet, and having a circumference of 42 feet. The water of this well filters through the sand from the Nile, and, being impregnated in its passage by salt and nitre, it has a brackish taste."

45. As a modern discovery, or, properly, revival, that of *Artesian Wells* is a valuable source of the artificial supply of water. The *theory* of these wells is simply this:—that water, descending through the permeable strata of the earth, and reaching either a cavity or a bed of spongy materials, will accumulate there if its egress is prevented by an impervious surrounding stratum; then, if an artificial opening or well be made into this water-bearing bed, the water will rise upward in it to a height, and with a force, due to the superior elevation and fertility of the source. Having been long adopted in Artois, these wells have received the modern name of Artesian wells. This contrivance appears to have been introduced into this country from France and Italy about the year 1790. At Mortlake, near the Thames, a well was driven through the clay and sand into a bed of soft chalk to a depth of 375 feet, and a good supply obtained through a bore of 3½ ins. in diameter. The strata penetrated were as follow:—gravel, 20 ft.

London clay, 250 ft.; plastic sands and clays, 55 ft.; hard chalk with flints, 35 ft.; soft chalk, 15 ft.

46. The celebrated Artesian Well at Grenelle, in France, formed under the direction of M. Mulot, is an instance of the difficulties and success of these works. This work occupied eight years and a half of anxious exertion, and the

Strata.	Total Depth from Surface.	Depth of each Stratum.	Corresponding with the London formations, viz.:—	Formations of London and Paris Basins.
	Feet.	Feet.		
Gravel and sand	13	13		
Cockle shells				
Quartzose sand, with fine particles of sulphuret of iron				
Fine sand				
Argillaceous sand	180	167		Plastic clay.
Mottled				
Clay				
Sand and clay, with nodules of limestone				
White chalk, with layers of flints	328	148		White chalk.
White chalk, alternating with strata of dolomite and small pieces of silex	886	558		
Gray chalk with particles of silex	1049	163		
Gray chalk compact without silex	1453	404		Gray chalk.
Green chalk and particles of the silicate of iron				
Blue argillaceous chalk	1634	181		Chalk marl.
Blue argillaceous and sandy chalk, with particles of mica, and veins of green chalk				
Clay with iron pyrites, nodules of the phosphate of lime and fossil débris				
Green sand	1794	160		
Clay and greenish sand, with grains of quartz				
Argillaceous sand				
Green and white sand				

water first rose on the 26th of February, 1841. The strata bored through are as shown in the table page 38—the depth being measured from the surface:—the second column shows the depth of each stratum, and the third column exhibits the resemblance between the formations of the basins of London and Paris.

The sand, in which the water is obtained, continues below this depth. The boring was commenced at a diameter of 20 inches, and diminished as the tubes descended, so that at the depth of 576 feet, employing 4 columns of tubing, the diameter was 12 inches. The fifth column of tubing reaches 1148 feet, with a diameter of 10 inches. The sixth reaches 1345 feet, and has a diameter of $8\frac{1}{4}$ inches. The seventh and last tube reaches 1771 feet, with a diameter of $6\frac{3}{4}$ inches. The lower 23 feet in the clay are not tubed. During the progress of the work several accidents of a discouraging nature occurred: the rods and chisels sometimes became detached, and fell to the bottom. The chisel also, when in the chalk, sank at one stroke 85 feet, and became so firmly fixed, that M. Mulot found it necessary to enlarge the hole on all sides. All difficulties were at length, however, surmounted, and on the day mentioned the rods suddenly sunk several feet; the workmen found that all resistance had ceased, and that the water-bearing stratum was attained. After a few hours a column of water rose to a height of nearly 2000 feet. The subsequent operation of lining the bore was a work of great importance, in order to prevent the sides of the hole falling in through any of the less compact strata, and at the same time prevent the possibility of the water escaping, or the pressure being lost by any fissures that exist, or may be formed in the strata through which the water passes. The arrangement of these tubes requiring a regular diminution of diameter in the manner of the tubes of a telescope, it is essential that the relative dimensions be calculated with great exactness, otherwise the lower tubes are found to become too small to admit the water, and it is then necessary to remove the

whole of the tubes deposited, and enlarge the bore accordingly. At Grenelle it was five times necessary to remove the whole of the placed lining, and enlarge the bore of the well. Wrought iron had been employed for lining on previous occasions, but had failed, one remarkable instance of which may be mentioned. The water of an Artesian Well at St. Cyr, near Tours, rises from the sand beneath the chalk, and the tubular lining to the well was of iron. The supply, however, diminished in every succeeding year, and M. Bretonneau caused the tubing to be drawn up, which was $\frac{3}{10}$ths of an inch in thickness, and found well preserved; but at the joints of the pipes several circular holes were discovered, two or three centimes in diameter. This effect has been accounted for by an assumed electro-chemical action, but, however caused, it led to the rejection of iron as a material for the tubing. Copper tubes $\frac{1}{10}$th of an inch in thickness have been applied at Grenelle.

47. The supply from the Puits de Grenelle was reported in 1841 to exceed 880,000 gallons every 24 hours, and the cost of the work was about £10,000. Some of the Artesian Wells sunk at Tours were found to yield less than when opened. A greater number, however, have produced an augmented quantity, and the probability is that the deficiencies have arisen from imperfections in the lining of the bores. In the province of Artois, where Artesian Wells have existed upwards of 300 years, no diminution has ever been observed. The subterranean sheet of water which supplies these, extends over a space of several hundred square leagues, in comparison with which the outlets to these wells are almost inappreciable.

48 The deficiency of supply by which Artesian Wells are rendered inoperative, usually becomes evident before any very great depth is reached, although, if the water-bearing stratum happens to crop out at any points however distant from the boring, the supply is liable to deficiency, and the pressure necessary to force the water upwards is also perhaps lost. Thus, previous to the operations at

Grenelle, just described, a boring was executed at the Jardin des Plantes; but the water never reached the surface, although it rose to within a few feet of it. This fact was afterwards accounted for by the discovery that the sheet of water which supplied this boring, being the same that feeds the fountains of St. Ouen and St. Denis, crops out on the banks of the river Seine, between Chaillot and Saint Cloud. From this sheet, that which supplies the wells at Tours and Elbœuf is separated by the entire chalk formation. M. Champoiseau communicated to the Academy of Sciences, in 1840, the result of experiments he had made at Tours, to ascertain if any connection existed between his Artesian Well and the neighbouring rivers. These experiments were conducted during the months of March, April, and May, while the waters of the rivers were fluctuating, but no corresponding change was found in the well-waters, which did not show any variation either in their quantity or clearness. The temperature of the water of Grenelle was found to be 81°·7 Fahr., and its quality far more pure than that of the Seine, or of Arcueil. From an analysis by M. Pelouze, it appears that 100 cubic inches of the Grenelle water gave only 3·5 grains of extraneous matter, whilst a similar quantity of water from Arcueil or the Seine yielded 4·3 grains mechanically suspended, and 11·6 grains of chemical impurities.

49. Borings similar to those for Artesian Wells have been executed for the purpose of getting rid of superfluous water and liquid matters. An embankment near Val de Fleury, for the left bank Versailles Railway, was drained in this manner by means of *absorbing wells*. A stratum of clay and sand soaked with the rains of the previous year forced the bank from its position, and destroyed the works. Borings were made, the first of which reached 20 yards in depth, where it arrived at the upper part of the chalk, full of fissures, and which speedily absorbed the water. The subsequent borings were carried to 35 and 40 yards, in order to reach the chalky fissures which communicate with the

Seine, and feed the neighbouring wells. Absorbing wells have also been used in France to dispose of the refuse of the lay-stalls. M. Mulot, who superintended the Grenelle Artesian Well, executed a boring for this purpose at Baudy. Through a perforation 244 feet in depth, two absorbing strata were obtained, one at a depth from 133 to 155 feet, in chalk mixed with silex, and the other from 210 to 244 feet, in argillaceous sand, and green and gray sands containing lignites and pulverized shells. By the first 70, and the latter 140 cubic yards of refuse liquid were absorbed.

50. The question of relative levels as affecting the practicability and expense of draining operations in the raising and removal of water and even of soils, has been rendered far less important by the application of steam-power. The expense of raising 43,000 gallons of water a hundred feet high by a Cornish engine of 25-horse power is only a shilling; and with an engine of 180-horse power, 80,000 gallons are lifted for that sum, coal being 12*s*. per ton. In the potteries, what is called "slip," that is, clay mixed with powdered flint and granite, with about one ton and a half of water to one ton of solid matter, is pumped and distributed;* and there is no doubt that where water is available, and where the operation required is on a sufficiently large scale, lands might be "clayed" and earths distributed much more effectually and cheaply by this than by any other method. The greater weight of the "slip" referred to, as compared with that of water, increases the labour of pumping about one-third.

51. The power of water in carrying matters in suspension is much neglected in agricultural as well as in engineering operations. Earths may, when properly diluted, be distributed, by the pump worked by steam-power, through a hose with open apertures, not only at a cheaper rate than by any other method, but in a far superior mode, being finely comminuted and evenly spread. In Germany, where

* General Board of Health.—"Minutes of Information."

water can be obtained at a high level, and gravitation can be used, improvements are effected by the distribution of earths on an extensive scale, the principle of the mechanical distribution by hydraulic power being the same as warping. In Tuscany the large work of the "*bonificamento*" of the *Maremma* is a work by means of water-power so applied by which upwards of two feet in thickness of solid earth has been spread over forty square miles of country; a mass of earthwork equal to nearly 82½ million cubic yards, regularly deposited as if rammed. On an estimate for some work on a large scale in this country it appeared that the working expense of spreading clay by means of a hose would be little more than 2*s.* 6*d.* per inch of depth per acre, equal to 134 cubic yards, the expense of carrying and spreading which, by man and horse-power, would have been very considerable.

52. The following example of the comparative expense of removal of earth by cartage and in suspension in water is given in the sanitary report:—"A contract was about to be entered into by the West Middlesex Water Company for hauling out from their reservoir at Kensington the deposit of eight or ten years' silt, which had accumulated to the depth of three or four feet. The contractor offered to remove this quantity, which covered nearly an acre of surface, for the sum of 400*l.*, in three or four weeks. The reservoir was emptied (of the water) in order to be inspected by the engineer and directors before the contract was accepted. It occurred to one of the officers that the cleansing might be accomplished more readily by merely stirring up the silt to mix it with water; and then, if a cut or outlet were made in the main pipe used for conveying the water to London, that it might be washed out. He accordingly got thirty or forty men to work in stirring up the deposit, and accomplished the work at the cost of 40*l.* or 50*l.*, and three or four days' labour, instead of so many weeks. When the directors went to see the basin, to decide upon

the contract, the reservoir was as free from any deposit as a house-floor."*

53. On the peculiar qualities of water depends its fitness for agricultural, manufacturing, and domestic purposes. Chemical researches have put us in possession of much valuable knowledge upon this subject, which it behoves the land-worker and the engineer equally to avail themselves of. Pure water, as proved by the early experiments of Priestley and Cavendish, about the year 1780, consists of the two gases, oxygen and hydrogen, in the proportion of 85 parts, by weight, of oxygen, to 15 of hydrogen. This pure liquid can be obtained only by distilling water as it is found in the several states of rain-water, river-water, sea-water, and spring-water. The water obtained from each of these sources contains foreign matters of some kind, the nature and effects of which, as ingredients in the water we have to employ, are well deserving our best attention.

54. Liebig has proved, by experiments made in the laboratory at Giessen, that rain-water contains ammonia. All the rain-water used for these experiments was collected at a distance of 600 paces (south-west) from the town, and while the wind was blowing towards it. Several hundred pounds of the water were distilled in a copper still, and, upon evaporating some of it with muriatic acid, an evident crystallization of sal-ammoniac was observed. The same eminent chemist has fully satisfied himself of the presence of ammonia in snow-water. By evaporating the snow with muriatic acid, crystals of sal-ammoniac were obtained; and from these crystals the ammonia was liberated by adding hydrate of lime. In these experiments Liebig observed that the inferior strata of snow always contained a larger proportion of ammonia than that lying upon the surface.

* Under the old practice, sewers were cleansed from deposit by buckets, and the deposit removed by cartage, at an expense of 10*s.* per load, by contract. By means of flushing, or by water, the cleansing and removal were effected at a cost of from 3*d.* to 8*d.* per load.

The origin of this ingredient and its utility in the vegetable economy are details of a most interesting study, but we cannot afford space to pursue the inquiry.

55. Sea-water contains, besides carbonic acid, ammonia, &c., the following salts:—according to Marcet,

Chloride of sodium	26·660
Chloride of magnesium . . .	5·152
Sulphate of soda	4·660
Sulphate of lime	1·500
Chloride of potassium . . .	1·232
	39·204

making a total of 39·204 parts of salts in 1000 parts of sea-water. An analysis of the water of the North Sea, made by Clemm, differs slightly from this. Clemm's is as follows:—

Chloride of sodium	24·84
Chloride of magnesium . . .	2·42
Sulphate of magnesia	2·06
Chloride of potassium	1·31
Sulphate of lime	1·20
	31·83

showing a total of 31·83 parts of salts in 1000 parts of sea-water. These salts are, by the constant evaporation from the surface of the sea, floated over the earth and carried down by the rain, thus replenishing vegetation with the salts essential to its growth and existence.

56. The waters obtained from rivers, springs, and wells, are all impregnated, in a greater or less degree, with foreign substances, and also hold others in a state of mechanical suspension. These impurities are of four kinds, viz.:—

1st. The Mechanical.
2nd. The Animal.
3rd. The Vegetable.
4th. The Mineral or Saline.

Although the purification of water from these matters may belong peculiarly to our Second Division, it will be well to consider it under the First, in order to establish correct notions of the qualities of water, whether applied to agricultural, manufacturing, or domestic uses. The process of filtration separates only the first of these. The saline matter contained in water may be distinguished as *neutral* and *alkaline*. The neutral salts are gypsum, common salt, &c. The alkaline portion consists of earthy bicarbonates, such as those of lime and magnesia, and alkaline bicarbonates, such as those of potash and soda The principal cause of that quality of water, termed "hardness," arises from the presence of the earthy salts mentioned, and sometimes iron-salts; and the same property is evinced if the water contains an excess of carbonic acid. Exposure to the air will diminish the hardness of water, as far as that quality is occasioned by the excess of carbonic acid; and it will have a similar effect, but in much diminished degree, upon waters which owe their hardness to the presence of the earthy bicarbonates.

57. The economical results dependent upon the qualities of the water supplied to towns are of extreme importance, and therefore deserve attention. Thus, the bicarbonates of lime, &c., affect, to a great degree, the value of water in its application to many manufacturing purposes, and to the production of steam and the heating of pipes for artificial warming. The incrustation of boilers is a well-known theme of consideration in the economy of steam-power, and, moreover, frequently becomes operative as the ultimate cause of accidents, in the case of explosions. In its domestic applications, the properties of water are equally important. The quality of hardness occasions a necessity for a great additional consumption of soap in all the processes of washing and cleansing. And this resistance to the cleansing action becomes, as is universally known, the cause of increased mechanical effort on the part of the operator, and a corresponding increase of wear and injury to the clothes

acted upon. Dr. T. Clark, who has given much attention to this subject, and is the patentee of a process for testing the hardness of water, conceives that a very considerable expenditure arises from these causes in a large town supplied with hard water.

58. For the purpose of comparison, Dr. Clark adopts the effect of the presence of one grain of chalk in one gallon of water as a standard, or *one degree of hardness;* and he gives the results of some of his analyses as follows:— The hardness of the waters supplied through pipes in London varies from 11° to 16°, or equal to the effect of 11 to 16 grains of chalk per gallon. The pipe-water of Manchester has 12° of hardness. The water of Glasgow 4°·5. Of Edinburgh about 5°. Newcastle-upon-Tyne Company's water, nearly 5°. Thames water near Mortlake had 14°·2 hardness, while the average of many trials upon Thames water, after conveyance through pipes, gave only 11°·8. The inference, therefore, is, that it had lost 2°·4 of its original hardness during its passage and exposure.

59. The outline of Dr. Clark's process may be gathered from the following abridged extract from the specification of his patent:—"Chalk forms the bulk of the chemical impurity that the process will separate from water, and is the material whence the ingredient for effecting the separation will be obtained. In water, chalk is almost or altogether insoluble, but it may be rendered soluble by either of two processes of a very opposite kind. When burned, as in a kiln, chalk loses weight. If dry and pure, only 9 oz. will remain out of 16 oz.; these nine will be soluble in water, but require 40 gallons for entire solution. Burnt chalk is called quicklime, and water holding quicklime in solution is called lime-water, and is clear and colourless. The 7 oz. lost by burning the 16, consist of carbonic acid gas, which, dissolved under compression by water, forms soda-water. The other mode of rendering chalk soluble in water is nearly the reverse. In the former mode, one pound of pure chalk becomes dissolved in water, in conse-

quence of losing 7 oz. of carbonic acid. To dissolve in the second mode, not only must the pound of chalk not lose the 7 oz. of carbonic acid, but it must combine with 7 additional ounces of that acid. In such a state of combination, chalk exists in the waters of London, dissolved, invisible, and colourless like salt in water. . . . . A pound of chalk dissolved in 560 gallons of water by 7 ounces of carbonic acid, would form a solution not sensibly different, in ordinary use, from the filtered water of the Thames, in the average state of that river. Chalk, which chemists call carbonate of lime, becomes bicarbonate of lime when dissolved in water by carbonic acid. Any lime-water may be mixed with another, and any solution of bicarbonate of lime with another, without any change being produced. But, if lime-water be mixed with a solution of bicarbonate of lime, the mixture acquires the appearance of whitewash, and chalk is precipitated, leaving the water above perfectly clear. This operation will be understood by supposing 1 lb. of chalk, after being burned to 9 oz. of quicklime, to be dissolved, and form 40 gallons of lime-water; that another pound is dissolved by 7 oz. of extra carbonic acid, so as to form 560 gallons of a solution of bicarbonate of lime, and that the two solutions are mixed, making up 600 gallons. The 9 oz. of quicklime from the 1 lb. of chalk unite with the 7 extra ounces of carbonic acid that hold the other pound of chalk in solution. These 9 ounces of quicklime and 7 ounces of carbonic acid form 16 oz., or 1 lb. of chalk, which, being insoluble in water, becomes visible at the same time that the other pound of chalk, being deprived of the extra 7 oz. of carbonic acid that kept it in solution, reappears. Both pounds of chalk will be found at the bottom of the subsidence. The 600 gallons of water will remain above, clear and colourless, without holding in solution any sensible quantity either of quicklime or bicarbonate of lime."

60. All the methods of mere mechanical clearing of water are one or other of two processes, viz., *settling*, or

subsidence, and *filtration*. The first of these processes is of a negative character, consisting simply in letting the water remain for a considerable period in an undisturbed condition. It is well known that, if a quantity of water, having particles of any foreign matters of greater specific gravity than water floating or diffused within it, be allowed to continue in a quiescent state for a sufficient length of time, these particles will subside to the bottom of the water, which is thus left comparatively clear and limpid. In order to accomplish this purpose on a great scale, reservoirs are constructed, in which the water is accumulated and permitted to remain, and from which it is delivered as required. Such reservoirs are termed *subsiding* or *settling* reservoirs.

61. The East London Water Company, which draws the water from the River Lea, near Lea Bridge, and supplies the eastern part of the metropolis and suburbs, has 20 acres of settling reservoirs. The arrangement is this:—The water is introduced through a canal, two miles long, into a wide canal, or small reservoir, at the end of which there are two sets of gates, each of which opens a communication with a separate reservoir. The water is admitted into both of these reservoirs, but drawn from only one of them at a time, the other remaining closed. Thus the water remains for one day in each reservoir alternately, while, in time of floods, it may be shut off altogether from these reservoirs for four or five days.

62. The value of all merely settling reservoirs can be derived only by drawing the water from the *upper* part of them. It is evident that, while the subsidence is going on, the whole bulk of the water is clarified only in proportion to its distance from the bed; and thus, the lower down that the point of exit is situated, the less clear must be the water that passes away.

63. To make the principle of subsidence fully effective, it is likewise necessary that the water should remain for some period, probably 24 hours at least, *entirely undisturbed.*

If any motion is permitted, the subsidence is interrupted, if not arrested. The reservoir should therefore be filled, and then totally closed both to ingress and egress. At the expiration of 24 hours, the upper part of the water should be *gently* drawn off. If the extent of supply will admit, the lower portion of the water may afterwards be let off for manufacturing or inferior purposes, or allowed to mingle with another fresh portion. If both the supply and the discharge be conducted at a sufficiently slow rate, and enough time be allowed for the quiet completion of the subsidence, the bulk of the water will always maintain a high degree of mechanical clearness, and the intermixture of the water remaining after each drawing off with the incoming water, will not involve any material loss of time in the process.

64. The process of *filtration* is effected by providing a bed of easily permeable materials, in which the water deposits the solid particles which it held in suspension, and finds its way to the lower bed in a comparatively clear state. The filtering materials employed in large filters are, sand and gravel of various degrees of fineness, pebbles, and shells. These latter, by their calcareous properties, act chemically on the water to a trifling extent, or while they retain free carbonic acid; the other materials admit the passage of the water, but prevent that of such solid particles as are larger than the interstices between the particles of the materials. The filtered water is collected in brick tunnels, constructed in the lower filtering stratum, and having apertures in the joints to admit the water. Fig. 3 is a section of a filtering reservoir as constructed for the Chelsea Water Company. In this reservoir the water comes in contact first with a bed of fine sand, *a*, which arrests the mechanical impurities. It thence passes through the strata, *b*, of coarse sand, *c*, of pebbles and shells, and *d*, of fine gravel, into the lowest bed, *e*, which consists of large gravel, lying upon a firm foundation of clay, 18 inches thick, and having the brick culverts, *f f f*, built within it. The

clay bottom must, of course, be rendered sufficiently compact to resist the passage of the water; and, if no clay be found, it will be necessary to form an artificial bed for the purpose. The collecting tunnels are here constructed of blocks of brickwork in cement, and partly open-jointed. They are three feet in diameter, and two half-bricks in thickness. The water is admitted to the filtering-bed at nine places, the ends of the supply-pipes being fitted with curved boards to diffuse the water, and prevent any disturbance of the upper stratum of sand. The quantity filtered in this bed, which is 240 feet long, and 180 feet wide, is 72 gallons per superficial foot of the filtering-bed daily, according to the demand. The undulating surface of the bed allows parts of it to be drained when necessary, without removing the water from the adjacent hollows. It is found that the sediment penetrates only from six to nine inches in depth, and the removal of one inch in thickness of the fine sand, every fortnight, is found sufficient to secure the proper action of the apparatus. Air-drains are provided to admit the escape of the condensed air which may collect in the tunnels. It has been found that it is necessary, in all cases, to remove the old sand before introducing fresh sand; otherwise a film is formed on the original sand which will resist the passage of the water.

65. The first and current expense of this system of filtration is estimated by Mr. James Simpson, the engineer of the Chelsea Waterworks, to be as follows:—

First cost of filtering-bed, exclusive of land . .	£11,700
Annual expense of raising water in filtering-bed . (From the River Thames, close adjoining, raised by steam engine.)	800
Annual expense of cleansing and renewal . . .	800
Five per cent. interest on outlay of capital . .	585
Total annual cost, exclusive of land . .	£2,185

The quantity filtered being 3,136,320 gallons daily, or 1,144,756,800 gallons annually, or at the rate of about 2183 gallons for one penny.

66. The system of cleansing adopted by the Southwark Water Company embraces settling reservoirs, as well as filtering-beds or reservoirs, and some peculiarities in the formation of the former deserve notice. The section, fig. 4, will clearly show the construction. A A are the settling reservoirs, having an area of between four and five acres, and being 13 ft. 6 in. deep, and faced with gravel. The bed was found to be springy in some places, and there lime was mixed with the gravel, forming an impermeable concrete. The beds are formed with a slight inclination from the sides towards the middle, along which an inverted arch, *b*, is formed of brickwork in cement, 6 ft. wide, and 3 ft. 6 in. deep. This invert is an essential improvement, and, with the inclined bed, gives great facilities for cleansing, by sweeping the deposits into the invert, and flushing it away with a current of water from an upper reservoir. The filters are constructed similarly to those of the Chelsea Works just described. The series of filtering substances consists of coarse gravel, 1 ft. deep; rough screened gravel, 9 in. deep; fine screened gravel, 6 in. deep; hoggin, or fine gravel, 9 in. deep; and fine wash gray river sand, 3 ft. 6 in. deep. The water is gradually drawn from the settling reservoirs, A A, on to the surface of the sand, on the filter-bed, C, and is permitted to percolate through brick culverts, formed with open joints in cement. The filtered water passes from these into close brick tunnels, by which it is conducted into the well of the pumping engine, D.

67. The expense of filtering by this, the Battersea filter, is stated by Mr. Joseph Quick, the engineer for the Works, not to exceed 350*l.* per annum, the quantity filtered being 2,160,000 gallons per diem, or 66 gallons per superficial foot. At this rate the annual quantity filtered will be 788,400,000 gallons, and the cost about one penny per

9386 gallons. At the Bleaching Works at Dukinfield, 500,000 gallons are filtered daily, at a cost of 156*l.* per annum, or at the rate of 4874 gallons for one penny.

68. Water which has been subjected to the process of subsidence only still usually contains finely-comminuted particles of solid matter, from which the subsequent process of filtration is necessary to cleanse it. The settling reservoirs having answered the double purpose of depositing the grosser solid particles, and of effecting all the chemical *softening* of the water which can be effected by mere exposure to the atmosphere, the filtering reservoir completes the process of depositing, and sends the water forward in a tolerably pellucid condition. But beyond these processes, and altogether irrespective of any chemical improvement of its constitution, it is found that water which has remained in an exposed reservoir, and subject to the action of light —made so much more effective by the transparency of the filtered water—does, in some states and temperatures of the atmosphere, betray unequivocal symptoms of vegetable formation within it, and, if the action proceeds, animal life, in the form of minute animalculæ, rapidly succeeds. It has therefore been suggested, that the filtering process could be still further improved, if the water were submitted to a subsequent passage through some filtering medium calculated to detain any such vegetable or insect productions as might be formed on the surface of the filtering-bed, and by chance find their way with the water into the tunnels beneath.

69. When water is drawn from a river having a sandy or gravelly bed in its vicinity, it is comparatively easy and inexpensive to form a natural and highly-effective filter. Thus, at Nottingham, the Reservoir, which is formed on the banks of the River Trent, about a mile from the town, is excavated in a stratum of clean gravel and sand, through which the water slowly percolates to a distance of 150 feet from the river. The deposited solid matter thus remains on the bed of the river, from which it is removed by the

natural action of the current. The reservoir being exposed to the solar influence, vegetation is sometimes produced, and which is removed at intervals of three weeks in summer, and six weeks in winter, by pumping out the water and sweeping. Besides the reservoir, there is a tunnel filter, which passes through a similar stratum for a considerable distance up the adjacent lands. This tunnel is 4 ft. in diameter, and half-brick thick, laid without mortar or cement, costing about 10*s.* a foot, including excavation to a depth of 12 feet.

70. An arrangement, somewhat similar to the last described, has been successfully carried out on the River Clyde, a few miles above Glasgow. At the selected spot there is an extensive round bank of sand. A tunnel was constructed in this bank parallel to the edge of the river, and also to the surface of the water and below the level of the water. This tunnel being constructed of bricks set in mortar below, but bricks without mortar above, received the water, which afterwards percolated into wells, from which it was pumped up for use. Similar natural filters were attempted at other points contiguous to the Clyde, but most of them failed, from the interception of springs of water of a harder quality than that from the river. In some cases, also, the natural springs intruded water containing iron, and injurious to the purposes for which the supply was required. Natural filters must, therefore, also be considered with reference to their liability of interruption by natural springs of a different or inferior quality. Beyond this, they should always be designed with a reference to the *lowest* level to which the river water may fall at any season, or under any circumstances; and this necessity sometimes involves a depth for the pipes, or other constructive difficulties, which altogether mar the economy and advisability of the arrangement. If this last precaution be not adopted, it will happen at the driest season of the year, when the maximum supply is required, that the reduced level of the river will be *below* the fixed level of the filtering tunnel,

which thus becomes dry and inactive. The only alternative which then remains is, to draw the water directly from the river, and thus the filter remains useless at the season when it is most desirable that it should be performing its highest duty. The work of cleaning the tunnels is, moreover, by no means an easy one; and, considering all the circumstances and liabilities of these expedients, it would appear that they are of very limited application.

71. Let us recapitulate the heads of the subjects over which we have already passed.

The sources whence the land is supplied with water, without artificial aid, are rain and tidal rivers, as in the Nile, Euphrates, Ganges, Mississippi, &c., besides such springs as rise spontaneously to the surface, either upward, by the pressure of internal reservoirs at a higher level, or at the outcrop of the strata of the earth. The artificial sources are the ocean, rivers, streams, and wells. The quantity of rain which falls over the earth appears to vary with the latitude, the distance from the ocean, the season, and other circumstances, the nature and influence of which we do not yet understand. The effect of the rain, as a source of water, and a cause of the necessity for drainage, is limited by the quantity which passes off from the surface of the earth in a state of vapour. The quantity so raised depends upon the temperature which prevails while the process of evaporation is going on. Efficient drainage requires the supply and the discharge of water to be duly regulated, the supply to be sufficient, and not in excess, and the discharge to proceed correlatively. The quantity required for the complete irrigation of a district is determinable by reference to the nature of the soil and the crops, and the position of the district in relation to surrounding tracts of country. The state of soil most favourable to vegetable growth is that of moistness, having water between the particles, but none between the clods or masses of earthy matter. Among the artificial sources of water, that yielded by the ocean requires chemical changes in order to

fit it for domestic purposes, and its applicability for those of agriculture is necessarily limited by remoteness. River-supply is attainable only for the adjacent lands of low level, unless it be forced up to the higher districts by mechanical means, which are afforded by steam-pumping at a comparatively small cost. The water of streams which are tributary to rivers is applicable for superior levels, and may, by judicious diversion and extension through artificial channels, be made widely useful. Wells are generally available by mechanical agency, and in some cases without it, provided a subterranean reservoir exists, and is subject to sufficient pressure from a higher source. All water at our command for practical use is more or less impure. Thus, rain-water contains ammonia, and sea-water a variety of salts. The water from rivers, springs, &c., contains several kinds of impurities. These impurities are dispelled only by a compound process, or rather series of processes, by which such matters as are mechanically suspended in the water are allowed to subside, or are arrested by filtering media, and the chemical impurities are absorbed and withdrawn by suitable agents. A brief notice of several varieties of filtering apparatus concludes this section of our first Division.

72. The filters already described, which, acting by the spontaneous percolations of the water through the apparatus, may be termed *self-acting*, have been further improved by adding means for their *self-cleansing*. The arrangements introduced for this purpose at Paisley, and other places, by Mr. Robert Thom, are illustrated, in principle, by the adjoining figures 5, 6, and 7. Fig. 5 is a plan, and figs. 6 and 7 sections taken at right angles to each other through the filter. In these filters, which are provided with layers of gravel and sand, the foul water is admitted at the top, and descends through these strata to undergo filtration; but the construction also admits of an occasional forced ascent of the water through these media, by which the foul particles are raised, deposited on the upper surface of the

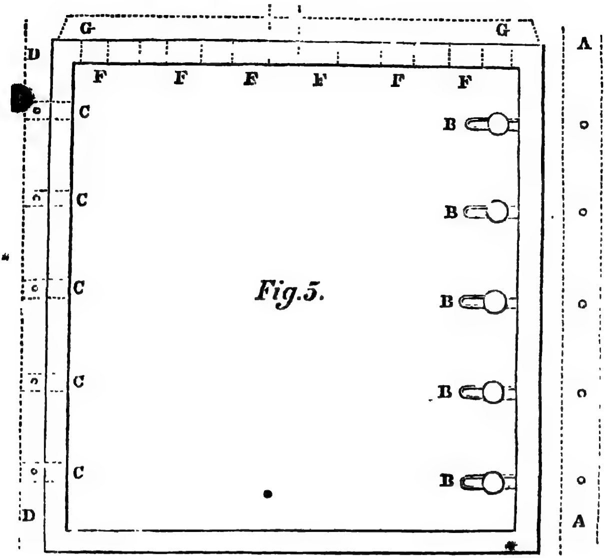


Fig. 5.

Fig. 6.

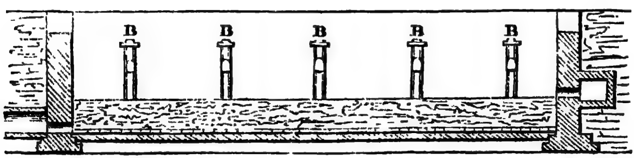
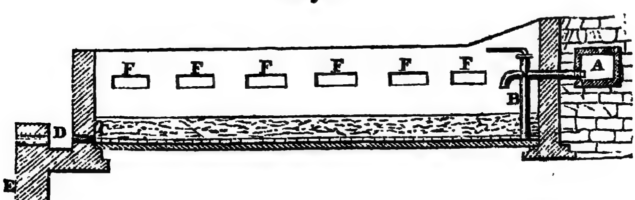


Fig. 7.



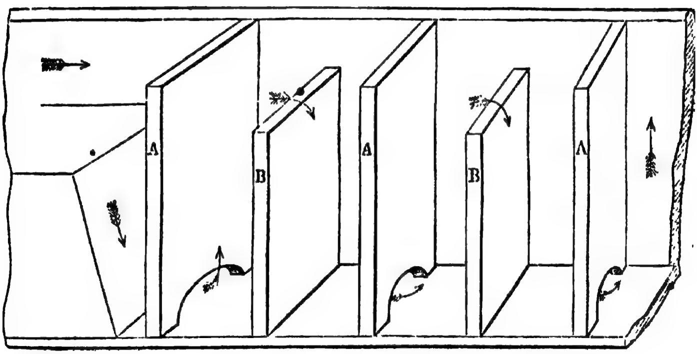
sand, and eventually carried away through a foul-water drain. The Paisley filter is 100 feet long and 60 feet wide, arranged in three compartments, each of which may be used separately while the others are cleansing. They are excavated, on a level site, to a depth of 6 or 8 feet, surrounded with retaining walls built in cement, and puddled behind. The bed is puddled 1 foot thick, and cemented pavement is laid upon it. It is then covered with fire-bricks laid on edge, and with spaces ¼ inch wide between them. These are covered with flat tiles, perforated with holes $\frac{1}{10}$th inch diameter. Over the drains thus formed, six layers of gravel, each 1 inch deep, and of finer particles than the one below, are evenly spread, and overlaid with 2 feet depth of clean, sharp, fine sand, the upper 6 inches of which are mixed with ground animal charcoal. The water is admitted through a stone pipe, A, and vertical iron pipes, B B, each having an upper and lower outlet to the filter. These pipes are fitted with valves, by which either of these communications is opened and the other closed. The clean water passes from the bottom of the filter through openings C C, fitted with stop-cocks, into a drain, D, and thence into the clean water basin, E. When the cleansing is going on, these connections are shut off, and access is given to the foul matter through holes, F F, to a drain, G. The cost of this filter was less than 600*l.*, and the quantity of clean water produced every 24 hours, on an average, is 106,632 cubic feet. Trap rock, from the hills above Greenock, has since been substituted by Mr. Thom for the charcoal with perfect success, and considerable economy: one part of the charcoal was mixed with eight or ten parts of the sand. The charcoal is sometimes laid in deep layers, without mixture, and is then worth reburning for a second use.

73. In the use of charcoal as a filtering agent, an attempt is made to effect something more than the mere mechanical clearing of the water by absorbing some of the gases with which it is chemically adulterated. How far this expedient

is valuable is, however, very questionable. The power of charcoal to act in this manner is well known to depend upon its being thoroughly and *recently burnt* and *dry*. Moisture diminishes this absorbing power, and in a short time the chemical action of the charcoal ceases. Some difference, doubtless, exists, in this respect, between animal and vegetable charcoal, but neither of them can be admitted as an effective chemical agent in the purification of water, without requiring a costly rapidity of renewal quite impracticable upon an extended scale.

74. With a view to promote the mechanical action of filters, many arrangements of internal partitions have been suggested. One of the best of these is exhibited in fig. 8,

Fig. 8.



and was successfully applied in Switzerland, by Sir Henry Englefield, upwards of forty years ago. This filter is divided into chambers by parallel partitions, A B, which admit the passage of the water alternately above and below them. The intermediate spaces may be filled with filtering materials of uniform quality. The course of the water must evidently be in the direction of the arrows; and the effect of this arrangement is, that the floating impurities are retained on the surface, while the heavier particles sink to the lower level.

75. An apparatus for close filtering, within an iron water tight box, has been introduced by M. Maurras; and its principal novelty consists in interposing the strata of fine sand between flat iron cases, perforated with holes and filled with sand of particles larger than the holes in the cases, with an arrangement of sluice-cocks, &c.; the process of cleaning was effected by sudden and violent currents of water.* A machine of this kind, 5 ft. 6 in. by 5 ft. 6 in., working under a head of water of 12 ft. 6 in., is said to have filtered an average quantity of 150,000 imperial gallons in 24 hours. A filter of this kind was tried for four months at the works of the New River Water Company, but the experiment does not appear to have been prosecuted, or the invention adopted.

76. In the year 1841, the Council of Health of Paris reported upon several processes which had been tried for filtering the waters of the Seine. The two principal plans noticed were those known as "Fonveille's" and "Souchon's." The apparatus used in the first of these consists of several layers of sponge, sand, and charcoal, disposed alternately in a close vessel. The filtration is accelerated by a considerable pressure upon the water. This arrangement was found to produce the most clear and least impure water; but, although this superiority was attributed to the charcoal, it was admitted that this effect required a very frequent washing, drying, and renewal of it. Souchon's process, which is most extensively used, consists in passing the water through layers of woollen tissue, formed of clippings of wool laid on the frames which form the bottom of the filter. The water filters through five of these layers, of which the two lowest are the thickest, and are changed at intervals of about five days. The upper layers are changed twice or thrice a day. The water thus filtered is stated to have been inferior to the other, but the quantity passed through was greater, being as 162 to 110.

SECTION II.

Upper and Lower Districts.—River-watered and Sea-coast Districts.—Reclamation of Land.—Modes of Draining, Pumping, &c.—Water-wheel as applied for Draining and supplying Upland Districts.

77. The principal division of districts and lands, as subjects for watering and draining, is derived from their relative levels. The sources at command and methods of proceeding for high and low tracts are perfectly dissimilar, and hence the natural and necessary distinction which is adopted as the head of this section. And as the plains and valleys are far more extensive in themselves than the hill tops and uplands, and equally superior in importance as recipients of the drainer's care, it is proper to turn our attention to them in the first instance.

78. In this first class, the Lower Districts, we propose to include the following varieties of surface, viz.:—1st, the low lands forming the margins of seas and rivers; and, 2nd, generally, the valleys in which natural watercourses have been formed, such as rivers, streams, &c.; 3rd, valleys in which lakes, or similar expanses of water, do or might exist, and which, with that adaptation, have a continuously-curved or basin-like contour; 4th, and plains which, although they may have a superior elevation to adjacent districts on one side, are correspondingly low in relation to the hills on the other. The sections sketched in the foreground of the figs. Nos. 9 to 12 will illustrate the relationship of levels referred to in each of these four varieties.

79. The watering and drainage of districts belonging to the first of these varieties (fig. 9) are frequently reduced to the sufficiently heavy task of getting rid of a large surplus of water which collects from the adjacent estuaries of large streams, or is detained in the form of evaporation from the surface of the sea, and condensed by low temperature. If the level of the district is above that of the sea and river-mouths, surface drainage, of properly-determined depth and extent, with ample main conducting channels, will suffice

Fig. 9.

Fig. 10.

to keep the land in a tolerably dry condition. An opportunity very seldom exists in such districts for tapping, or getting rid of the excess by opening a communication with a lower and permeable stratum. Rock in some cases, and bog in others, usually form the inferior deposits. If the former, surface draining is certain of success, although the construction will probably be expensive; but if the sub-

Fig. 11.

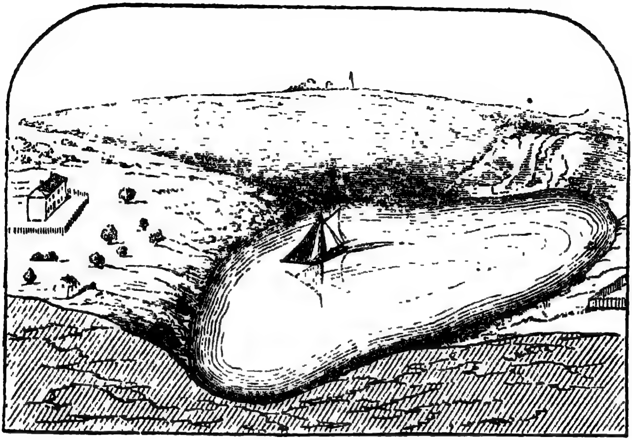


Fig. 12.

stratum be bog, and its bed below the river or sea level, boring to lower strata is presented as the only chance of success.

80. If, however, the level of the district be below that of the contiguous waters, it will be manifestly impossible to dry the land without embanking. And it will be necessary either that this work be sufficiently substantial to prevent the ingress of the water, or that the surface of the land be simultaneously raised artificially until it has a superior level, or that mechanical means be constantly employed to pump out the surplus water. Our own island has been preserved in its borders, nay, extended, by works of this class, which we shall now have to notice.

81. In pursuing this branch of our subject, we have the great gratification, through the kindness of Mr. Weale, of referring to one of the earliest and most interesting records of engineering art in this country—the celebrated account of the Fens, by Sir William Dugdale, the earliest edition of which was published in the year 1652, and the second edition, in folio, which we have consulted, in the year 1772, under the care of Charles Nelson Cole, Register to the Corporation of Bedford Level. Dugdale had been in the employment of the Corporation since the year 1643, and "published this History of Imbanking and Draining, at the request of Lord Gorges, who at that time had the principal direction of their works, and was, after their incorporation, for many years their Surveyor-General." The first sixteen pages of Sir William's book are occupied in brief notices of foreign works of this kind, beginning with Egypt, and thence passing to Babylon, Greece, and Rome, quoting his authorities from Herodotus, Strabo, Pliny, and others, and ending with Holland and the Netherlands. We cannot forego one short extract in reference to the troublesome Tiber, whose later tricks, we all remember, plunged so many of the poor Romans in ruin. Our quotation shows that, even in the time of Tiberius, public improvements were scandalously thwarted, as they are in our own day, by the petty jealousies of cities and corporations. "To restrain the exorbitant overflowing of this stream (the river Tiber), which was not a little choaked with

dung and several old buildings that had fallen into it, I find that Augustus Cæsar bestowed some cost in the clearing and scouring of it; and that after this, through abundance of rain, the low grounds about the city suffering much by great inundations thereof, the remedy in preventing the like for the future was, by the Emperor Tiberius, committed to the care of Ateius Capito and L. Aruntius. Whereupon it was by them discussed in the senate, whether, for the moderating the floods of this river, the streams and lakes, whereby it increased, should be turned another way; but to that proposal there were several objections made from sundry cities and colonies; the Florentines desiring that the Glanis might not be put out of its accustomed channel, and turned into the river Arnus, in regard much prejudice would thereby befall them. In like manner did the inhabitants of Terano argue; affirming that, if the river Nar should be cut into smaller streams, the overflowings thereof would surround the most fruitful grounds of Italy. Neither were those of Reate (a city in Umbria) silent, who refused to stop the passage of the lake Uelinus (now called Lago de Terni), into the said river Nar. *The business, therefore, finding this opposition, was let alone.* (*!*) After which, Nerva or Trajan attempted likewise, by a trench, to prevent the fatal inundations of this river; but without success."

82. The earlier works of the Dutch were well followed up by the contemporaries of Dugdale. He describes their works "within the space of these last fifty years" to have included the "draining of sundry lakes, whereof sixteen were most considerable, by certain windmills, devised and erected for that purpose. The chiefest of which lakes, called the Beemster (containing above eighteen hundred acres), is made dry by the help of LXX of those mills, and walled about with a bank of great strength and substance." "The other lakes, so drained, as I have said, do lie about the cities of Alcmare, Horne, and Purmerende; and are vulgarly called de Schermere, de Waert, de Purmer,

and de Wormer." "Neither have the attempts of these people, by the like commendable enterprises, in South Holland, about the cities of Leyden, Dort, and Amsterdam, had less success, there having been divers thousands of acres, formerly overwhelmed with water, made good and firm land, within these few years, by the help of these engines." We shall have more to say by-and-by of the Dutch draining, as further extended within our own times, but meantime pass on to a notice of our own works in a similar department.

83. Dugdale shows, by "circumstantial testimonies," that the Romsey marshes were reclaimed by the Romans, and then quotes the ordinances of Henry III., "that all the lands in the said marsh be kept and maintained against the violence of the sea, and the floods of the fresh waters, with banks and sewers." The execution of these ordinances appears to have provoked much litigation, and Edward I. found it necessary to issue letters patent for the repairing of the banks and ditches. Further disputes followed, and led to new letters patent two years afterwards. Edward II., Edward III., Richard II., and several succeeding sovereigns, repeated their patents for the like purpose. Similar Royal commissions were instituted for preserving the lands in East Kent, "for the digging of a certain trench, over the lands, lying between Gestlinge, and Stonflete, and from Stonflete to the town of Sandwich; to the intent that the passage of the water called Northbroke, which was at Gestlinge, should be diverted; so that it might run to Sandwich." Also "for the repair and safeguard of the banks and ditches, from the overflowing of the tide, betwixt Dertford, Flete, and Grenewich," and thence to London Bridge. The banks, &c., in Surrey, "betwixt Lambehethe and Grenewiche;" of Middlesex, "betwixt the hospital of S. Kathrine's, near the Tower of London, and the town of Chadewelle;" some parts "within the precincts of Westminster;" "betwixt a place called the Neyt and Temple Bar, in London, then broken and in decay by the force of

the tides," were also to be repaired by Royal letters patent; besides the marshes in the suburbs of London, in Essex, and in Sussex. On the coasts of Somersetshire, Gloucestershire, and Yorkshire, &c., works of repair were also provided for under the care of Commissioners, severally appointed by letters patent from the kings. Of Somersetshire, Dugdale observes, "that the overflowings, both of the sea and fresh rivers in some parts of this country, were heretofore likewise exceeding great. I need not seek far for testimony; the rich and spacious marshes below Wells and Glastonbury (since, by much industry, drained and reduced to profit) sufficiently manifesting no less. For, considering the flatness of those parts, at least twelve miles eastward from the sea, which gave way to the tides to flow up very high; as also that the filth and sand, thereby continually brought up, did not a little obstruct the out-falls of those fresh waters which descend from Bruton, Shepton Malet, and several other places of this shire, all that great level about Glastonbury and below it (now for the most part called Brentmarshe) was, in time past, no other than a very fen; and that place, being naturally higher than the rest, accounted an island, by reason of its situation in the bosom of such vast waters."

84. The history of the works of embanking and draining in the counties of Lincoln and Cambridge affords evidence of the skill and labour which had then been applied to these objects. The good abbots appear to have acted as conservators of the low lands in Lincolnshire. Thus, in the isle of Axholme, "one Geffrey Gaddesby, late abbot of Selby, did cause a strong sluice of wood to be made upon the river of Trent, at the head of a certain sewer, called the Maredyke, of a sufficient height and breadth for the defence of the tides coming from the sea; and, likewise, against the fresh waters descending from the west part of the before-specified sluice to the said sewer, into the same river of Trent; and thence into Humbre:" "John de Shireburne," Geffrey's successor, pulled down this timber

sluice, and "did new make the same sluices of stone, sufficient (as he thought) for defence of the sea tides, and likewise of the said fresh waters;" but jurors, appointed under patent of Henry V., reported that these stone sluices were "not strong enough for that purpose, being both too high and too broad; and that it would be expedient, if the then abbot would, in the place where those sluices of stone were made, cause certain sluices of strong timber to be set up, consisting of two flood-gates, each flood-gate containing in itself four foot in breadth, and six foot in height." They also recommended "one demmyng" to be made, "without the said sluice, towards the river of Trent."

85. It was upon districts such as those we are now considering that the art of draining was first practised. Here the matter was one of obvious necessity. In wet fields and moist pastures, our ancestors found no positive demand for improvement; the evil was seen and recognised in its full extent, but the only tangible effect was to depreciate the value of the land, and induce a preference for districts where nature provided a more sufficient drainage. But on the sea-coast, and especially in the neighbourhood of the outfalls of rivers, the evil of neglect was too apparent to be disregarded; the ocean spread over its common bounds, and the waters of the river, choked up with silt, passed their limits, the pasture fields became swamps,—in some cases the land disappeared by degrees, and the inheritance of ages became merged in the boundless waters.

86. The first work was to cut channels at intervals through the threatened district (selecting the lowest levels for them, where a choice was afforded), in which the excess of water might be collected and conducted to a main drain cut parallel to, or at an angle with, the coast or river, the transfer of the water from one to the other, and from the main to the sea or river, being, when necessary, regulated by sluices. The earth removed from these collecting and main drains, being cast up on either side of them, at once increased their available depth, formed boundaries to the

passing water, and raised causeways for the passage of men and animals. Thus arose the combined arts of draining and embanking.

87. The maps of the fens of Cambridgeshire and Lincolnshire exhibit a multitude of illustrations of the works here referred to; but we may select those executed in one district as examples of the whole. This district consists of the lowland or level about the river Ancholme in Lincolnshire, and is situated on the south side of the river Humber, about ten miles below its junction with the river Trent, containing about 50,000 acres of land. It is bounded on the east by a ridge of chalk hills, which extend from the Humber nearly 24 miles N. and S. From this ridge the Ancholme receives the drainage of about 100,000 acres. A lower ridge of oolite and sandy limestone divides it on the W. from the Trent Valley, and contributes to the Ancholme the drainage of some 50,000 acres more, and on the S. a low diluvial ridge divides the district from the Witham Valley. The Ancholme thus receives the drainage of a total of 200,000 acres. The valley varies from one to three miles in width, and the total bulk of waters daily poured through the river is estimated at 140 millions of cubic feet, being sufficient to cover the entire level to a depth of 2¼ inches. The principal portion of the district lies below the level of high water spring tides in the Humber, being in some places as much as 9 feet below that level. From a map of the valley published in Dugdale, and bearing date in 1640, it appears that the course of the Ancholme was originally very tortuous, being probably enfeebled and choked up by the alluvial deposits from the overflowing of the Humber. At that time, however, a straight channel had been cut, extending from the Humber to Glentham Bridge (a distance of 18 miles), and several drains formed, leading to the new Channel. Figs. 13 and 14, which are reduced sketches of the plan and section given by Dugdale, show the general direction of the old and new channels, and the drains as they existed in 1640. In the previous

year Sir John Munson became the undertaker for improving the draining works of this district, having a period of six years allotted for their execution, and a part of the lands, extending to 5827 acres, assigned to him, free of all commons, titles, charges, interest, and demand, of all or any persons whatsoever.

88. In the year 1801, the late Mr. Rennie reported upon the best means of completing the drainage and navigation of the level; and recommended that the drainage of the high lands should be separated from that of the low lands by main drains, commonly called *catch-water drains*, formed at a higher level than the others, and arranged with separate sluices for discharging into the Humber. This recommendation was well founded on the observation that the greater force and rapidity with which the waters from the upper districts reached the river than those from the lower, had the effect of driving the latter over the level, the sluices being inadequate to discharge the entire bulk of water during the periods while the river-tide permitted the sluice doors to remain open. Another and highly-important purpose which the catch-water drains fulfil, is that of providing a reserve supply of water which, during dry seasons, may be applied to the lower lands, thus promoting the objects which in those districts are usually associated with drainage, viz. irrigation and navigation. Mr. Rennie had already adopted a similar system of drainage on a more extensive district, that of the East, West, and Wildmore fens, near Boston; but his Report upon the Ancholme level was not then adopted. Twenty-four years later, however, an Act was obtained, viz. in 1825, for effecting improvements recommended by Sir John Rennie, and comprising the formation of the catch-water drains, as proposed by his late father in 1801. Sir J. Rennie advised that the river Ancholme should be straightened, widened, and deepened, so as to double its capacity; that a new sluice be formed at Ferraby, having its cill 6 ft. lower than the old one; together with a new lock, 30 ft. wide, so as to serve the double purpose of ad-

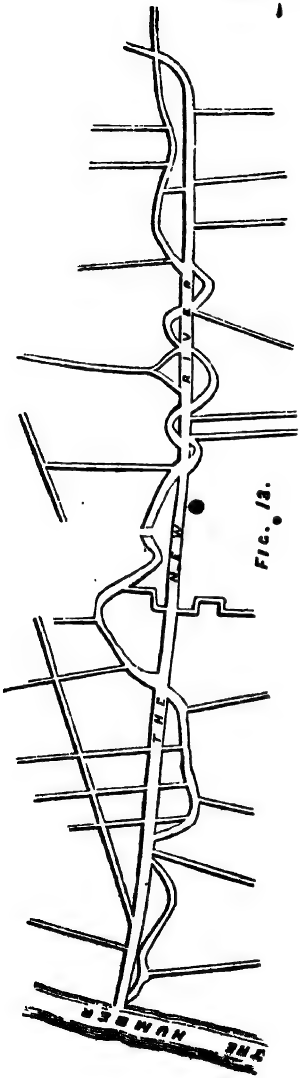

THE NEW RIVER
THE HUMBER

FIG. 13.

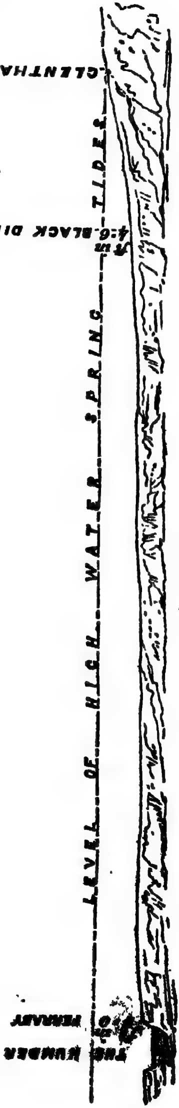
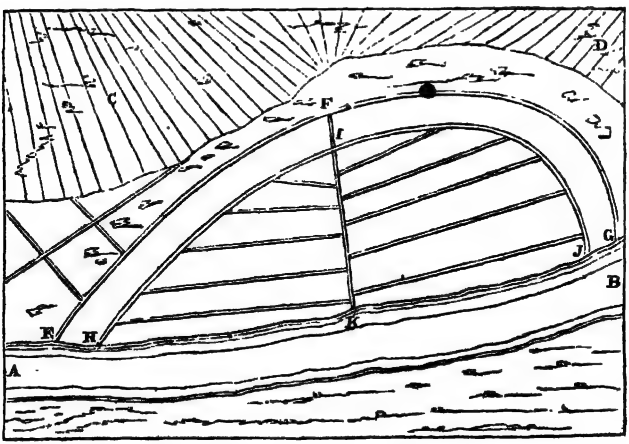

LEVEL OF HIGH WATER SPRING TIDES
GLENTHAM
4:6 BLACK DIKE
THE HUMBER

FIG. 14.

mitting larger vessels, and affording a greater discharge for the drainage waters during floods: that all old bridges which obstructed the flow should be removed, and a new lock be formed 18 miles above Ferraby sluice. These several works were executed accordingly, and the entire level of Ancholme has been converted into a rich arable district, capable of producing superior crops of every kind. Sir John Rennie also recommended the formation of reservoirs, with overfalls and weirs to receive the sand and mud brought down from the upper part of the country, and thus prevent its accumulation in the river.

89. Fig. 15 will give a general idea of an arrangement of

Fig. 15.



drains, which will be suitable for a level district with high land behind it. In this fig. A B is the river, and C D the high land. E F G represent a catch-water drain for receiving the waters from the high land; H I J, a parallel main drain for the level, with another main drain I K. Between the main drains the level is intersected with minor drains, which have a fall either way towards the mains. The

catch-water drain is adapted to discharge directly into the river; or by closed sluices at E G, and an open one at F, its contents may be directed into the main level drain at I, and made to assist the irrigation of the level in dry seasons. Sluices will be required at E, F, G, H, I, J, and K, by the regulation of which the water may be collected and disposed of in any manner required for the preservation and improvement of the district.

90. Figs. 16, 17, and 18 represent sections of drains of

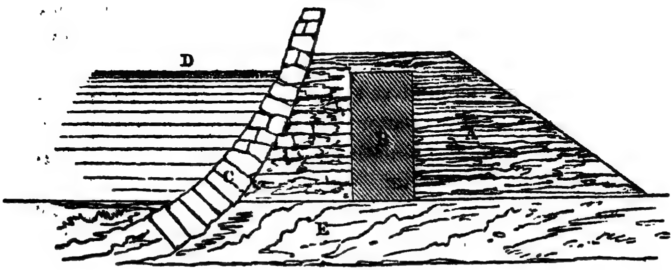
Fig. 16.

Fig. 17.

Fig. 18.

large size, adapted for works of the kind here referred to. Drains of these sections, formed with a fall of 18 in. per mile, will discharge as follows:—fig. 16, 10-ft. drain, will discharge 1193·4 cubic feet per minute; fig. 17, 15-ft. drain, 2880 cubic feet per minute; and fig. 18, 18-feet drain, will discharge 4642 cubic feet per minute. A good section for an embankment against the sea for these works is shown in fig. 19, in which A represents the embankment of earth; B, a solid wall or dyke of puddle; C, a facing wall

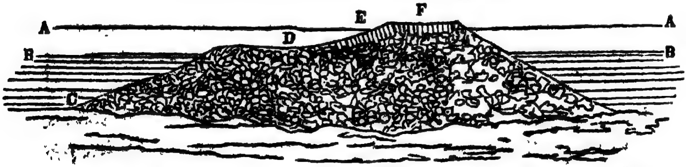
Fig. 19.



of masonry; D, the high-water level of the sea or bay; and E, the natural bed. The form of the front wall must be adapted to resist the action of the waves, and the embankment must have an internal slope, according to the nature of the materials of which it is composed: for ordinary materials, a base of 1·5 to a perpendicular height of 1 will insure the necessary stability and firmness.

91. If the entire embankment be formed of loose stones, with occasional facing only of laid masonry, as in the case of the celebrated breakwater at Plymouth, a form of less steepness must be adopted for the river front of the embankment. By way of illustration we may refer to fig. 20,

Fig. 20.



which shows a section of the Plymouth breakwater. The line A A shows the level of high-water spring tides; B B, low water spring tides; C C, original bottom, varying from 40 to 45 feet below low-water mark; D, the fore shore; E, sea slope; F, top, 45 ft. wide. The mass of the work is composed of limestone, from the Overton quarries, distant four miles from the spot. The stone is raised in blocks varying

from one quarter to ten tons and upward in weight, which are promiscuously thrown into the sea, care being taken that the greater number of the large blocks are thrown upon the outer or sea slope, and that the whole are so mixed together as to render the mass as solid as possible, the rubbish of the quarry and screenings of lime being flung in occasionally to assist the consolidation of the materials. The form of the outer slope, below low-water line, has been effected by the action of the sea, and is ascertained to be at from 3 to 4 feet of base to 1 of perpendicular altitude. From low water upward the work has been set artificially and inclined at 5 to 1. The inner slope next the land is nearly 2 ft. base to 1 altitude. The foreshore shown at D, which is from 30 to 70 ft. wide at different parts of the work, rises from the toe of the slope, to a height of 5 ft. above low water at its outer extremity, and serves to break the waves before they reach the main work; thus diminishing their force, and, at the same time, preventing the recoil of the wave from undermining the base of the slope.

92. The several sluices, gates, &c., constructed for the Ancholme drainage, being of the best description, may be briefly described as applicable for similar works in future. The *sluice* at Ferraby consists of three openings, each 18 ft. wide, with cills 8 ft. below that of the old sluice, and from 2 to 3 ft. below low water of spring tides in the Humber. The *lock* is 20 ft. wide in the clear, and 80 ft. long between the gates, giving a clear water-way of 74 ft., with an additional fall of 8 ft. The masonry is of best Yorkshire stone; and the foundations, which are in alluvial silt and clay, are upon piles 12 in. diameter, of beech, elm, and fir, from 24 to 28 ft. in length, and fitted with wrought iron hoops and shoes. When the piles were driven and the heads levelled, the earth was excavated to a depth of 2 ft. below them, and the spaces filled with blocks of chalk rammed soundly in, and grouted with lime and sand. Cap-cills of Memel fir, elm, or beech, 12 in. square, were fitted on the pile-heads

and firmly spiked down, the intermediate spaces being afterwards filled with solid brickwork, set and grouted with best Roman cement. The whole was then covered with a 3-in. flooring of Baltic fir-plank, bedded in lime, pozzolana, and sand. Inverted arches of solid stonework, 18 in. deep at the crown, are built upon this platform, and the work carried upon them. Two *sluice gates* were provided for each opening in the sluice, with *draw-doors* fitted in a water-tight groove by means of pinions, of wrought iron, which work in screws connected with vertical rods. These draw-doors are for regulating the navigation level (which is 13 ft. 8 in. above the cill), and to preserve a depth of 8 ft. 9 in. at Brigg, which is 9 miles distant, and 6 ft. 6 in. at Haarlem Hill lock, 18 miles distant. The *gates* are self-acting, being shut by the tide, and opened by the head of fresh water as soon as the tide falls below the level of the inside water. Four pairs of *lock-gates* were provided for the lock; two pairs pointing to the sea, and of sufficient height to exclude the highest tides: the other two pairs, pointing to the land, are high enough to control the navigation of the level. These gates were wholly constructed of the best English oak, well fitted together with wrought iron straps and bolts. The lock is filled and emptied through side culverts in the masonry, provided with cast-iron sluices, sliding upon brass faces, and worked with pinions and screws of wrought iron. The works also included several bridges of various spans and forms of construction.

93. In the application of *catch-water drains* it is preferable to discharge their contents at a higher point of the river, or main receiving channel, than that at which the low land drains are emptied. This principle was very successfully adopted by the late Mr. Rennie, in the drainage of the East, West, and Wildmore Fens, bordering on the river Witham, and comprising about 75,000 acres. The drain for the high land waters was made to discharge into the Witham, at a distance of three miles above the discharge of the low land waters.

94. The drainage of a low fenny district being arranged as far as the judicious selection of separate channels for the high and low lands, and provision made, with sluices, &c., for their communication with each other and with the river at pleasure, it remains to consider the state in which this river must be maintained in order to give efficiency to the internal system of drains by which the district is traversed. For this purpose it is evidently necessary that the channel be adequate in dimensions and suitable in form to maintain an active and sufficient current through it, and these conditions require a direct course and proper fall for the channel. If the direction be tortuous, the projecting banks will be washed into the bed and impede the flow of the current, and if the bed be on a dead level, or have an inadequate inclination, the flow will be sluggish, and lend no assistance to the discharge. Besides these conditions, it is necessary that the outfall of the river into the sea be of ample dimensions and unencumbered with shoals, bars, or other solid accumulations. These arise from the depositions of alluvial matter, which is liable to be brought in by the tides from the neighbouring coast, and also brought down with the drain-water from the interior country. This matter remains suspended in the water until the velocity is diminished, which generally occurs at the entrance to the river, owing jointly to the reduced inclination of the river bed near the sea, and the resistance suffered from the wind and waves, and it is then deposited, and by continual augmentation forms a fatal obstruction to the efficiency of the current. To determine the precise fall or inclination required for the bed of the channel, many experiments have been tried, but it will evidently be, to a considerable extent, controlled by the obstructions which may exist to the discharge of the waters. If the outfall be unimpeded, 4 or 5 in. per mile will be sufficient fall, but if obstructions exist, in the form of old bridges, sinuosities, &c., from 12 to 18 in. per mile will be found requisite.

95. Among the notable works of this kind which have been executed in this country, we may mention those for

improving the rivers Ouse and Nene. The chief defect in the former existed above the town of Lynn, where the river turned almost at right angles to its general course, and in a length of $5\frac{1}{2}$ miles formed a semicircle of only $2\frac{3}{4}$ miles in diameter. The channel was, moreover, so irregular in width and encumbered with shifting sands, that the tidal and drainage waters were unable to force a passage, and disastrous inundations were the results. In the year 1724 this evil was understood, and a proposition made by Bridgeman for improving the river by making a direct cut which should intercept the bend here described. Succeeding engineers concurred in this recommendation; but it was not until the year 1817 that an Act was obtained for executing this important work, which was named the Eau Brink Cut, and confided to the late Mr. Rennie. The works were finished on the 19th July, 1821, and have proved highly successful, lowering the low-water line in the river several feet, and completing the drainage of mere than 300,000 acres of land.* A work of similar character was executed in the year 1829, by Telford and Rennie, at the outfall of the river Nene, which commences about five miles below Wisbeach, and terminates after a length of five miles in the great estuary of the Wash. The benefits of this improvement have been very great; the low-water mark has been lowered 10 ft. 6 in., and a district of more than 100,000 acres, formerly a stagnant marsh, has been brought into cultivation.

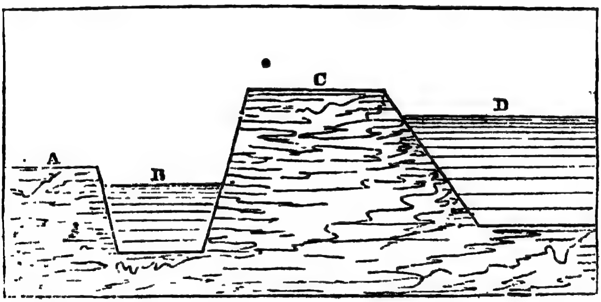
96. Closely allied with the drainage of low lands are the operations by which their boundaries are extended, and large districts actually *reclaimed* from the action of the sea. This is effected by judiciously controlling the deposit of the alluvial materials which are washed down with the drainage waters and thrown back by the tide. This requires the formation of embankments or opposing barriers, by which the removal of those materials is prevented. A

* The Great Level of the Fens contains about 680,000 acres, formerly of little value, but now rich in corn and cattle.

similar artificial mode of depositing the solid matters contained in the water is practised in the interior districts by surrounding them with embankments, and admitting and discharging the water by means of sluices and canals. This method has for many years been adopted with great success in the rivers Trent, Ouse, and Humber.

97. Districts lying below the level of the adjacent river, or so little above it that drains of adequate capacity must have their beds below the water line, necessarily require artificial means of discharging the drainage waters into the receiving channel or river. In the low lands of Holland this is commonly the case, and accordingly we find the Dutch were early adopters of contrivances for this purpose. Fig. 21 shows the relative conditions of the drain and of

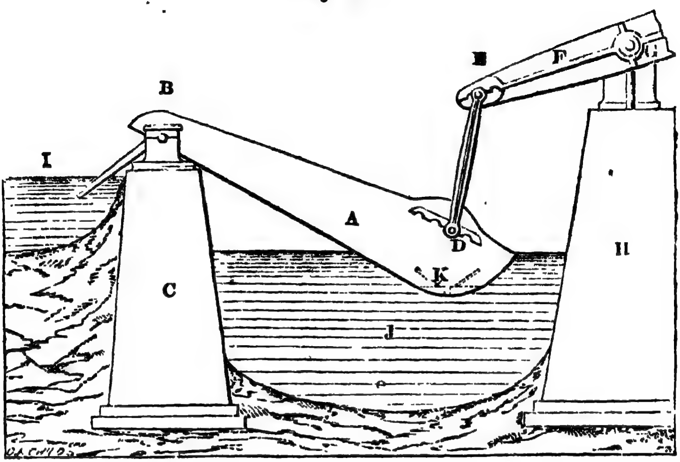
Fig. 21.



the river into which its contents are required to be discharged. A represents the general level of the district; B, that of the water in the drain to be discharged; C, the top of embankment; and D, the high-water level outside. To transfer the contents of the drain B into the main channel D, it is, evidently, only necessary to erect upon the embankment, pumps, buckets, or scoops, which shall bring the water up on the one side and discharge it on the other. Among the earlier machines employed by the Dutch were *scoop wheels*, which they worked by means of windmills, and continued to use for many ages.

98. A new form of scoop or alternating trough has been designed by Mr. W. Fairbairn, and adapted to be worked by the single-acting Cornish engine. Fig. 22 will serve to

Fig. 22.



give a general idea of this contrivance. A is the bail scoop, turning on a centre at B, fixed on the embankment C. The other end of the scoop is connected at D by a connecting rod with the end E, of the engine-beam F, of which G is the centre, and erected upon suitable foundations, H. I represents the level of water in the river, and J, the drain from which the water is to be discharged. The action of the apparatus will be evident from inspection of the figure. The engine employed is of the reciprocating kind, and by raising a weight suspended at the other end of the engine-beam F, the bailing scoop A descends, and becomes filled with the drainage water through the opening valves at K. The weight having been raised to the height of the stroke, descends by its own gravity, and raising the end, D, of the scoop, discharges its contents into the river at I. This apparatus is well adapted to be worked by the single-acting

Cornish engine, and while the length of stroke in the cylinder always remains the same, the dip is regulated as required by shifting the connecting rod at the ends D and E. The scoop is made of iron boiler plates, and is 25 ft. long and 30 ft. wide, with two partitions across it to strengthen the sides and afford bearings for the valves at K. The machine is adapted to raise 17 tons of water at each stroke, and, with an engine of 60-horse power, will do a duty equal to 3 lbs. of coal, per horse power, per hour.

99. The greatest improvement, however, effected in mechanical draining is by the employment of the steam engine for this purpose. In the year 1820, Rennie applied one of Watt's engines to the working of a large scoop wheel for draining Bottisham Fen, near Ely. Since that time large districts have been efficiently drained by steam power; and of them we may enumerate the following:—

	Containing	Drained by	
	Acres.	Engines.	Horse power.
Deeping Fen, near Spalding, Lincolnshire	25,000	2	80 and 60
Marsh West Fen, Cambridgeshire	3600	1	40 „
Misserton Moss, with Everton and Graingeley Carrs	6000	1	40 „
Littleport Fen, near Ely (75 wind engines were employed in this district before steam was used.)	28,000	2	30 and 40
Middle Fen, Cambridgeshire	7000	1	60 „
Waterbeach Level, between Ely and Cambridgeshire	5000	1	60 „
Magdalen Fen, near Lynn, Norfolk	4000	1	40 „
March Fen district, Cambridge	2700	1	30 „
Feltwell Fen, near Brandon	2400	1	20 „
Soham Mere, Cambridgeshire (Formerly a lake: the lift is here very great.)	1600	1	40 „

100. If the drainage from the high lands be discharged through catch-water drains, that from the low levels will consist of the rain water only, and as this, in the fen districts on the eastern side of England, seldom exceeds the

average of 26 in. in depth per annum, of which a large quantity is carried off by evaporations and absorption, 2 in. in depth or 1½ cubic ft. of water on every square yard of surface is the ordinary maximum quantity to be lifted per month. Adopting the admitted standard of horse-power, viz. 33,000 lbs., raised one foot per minute, and the weight of a cubic foot of water to equal 62½ lbs., or 10 lbs. per gallon, a horse's power will raise 300 gallons, or 52·8 cubic ft. of water 10 ft. high per minute. The total quantity to be raised per acre per month, viz. 7260 cubic ft., may thus be raised a height of 10 ft., and discharged in about 2 hours and 10 minutes. Upon this calculation, which Mr. Glynn (a high and practical authority in these matters) has found to be supported in practice, it appears that a steam engine of 10-horse power will raise and throw off the drainage water due to a district of 1000 acres of fens, in each month, in 232 hours. or less than 20 days, working 12 hours a day. The scoop-wheels used for raising the water resemble an undershot water-wheel, but, instead of being moved by the force of the water, they are adapted for forcing the water upward, deriving their motion from the steam engine. The float boards or ladle boards are of wood, and fitted to work within a track or trough of masonry: they are usually about 5 ft. long, that is, they are immersed in the water to that extent, the width or horizontal dimension of them being varied, according to the power of the engine and the head of water to be provided for, from 20 in. to 5 ft. The lower end of the wheel track communicates with the main drain, and the higher end with the river, the water of which is excluded by a pair of doors, pointing like the gates of a canal lock, and closed when the engine ceases to work. The wheels are of cast iron, and fitted in parts. The float boards are attached to the wheel by oak starts, stepped into sockets cast in the periphery of the wheel for that purpose. The wheel is fitted with cast-iron toothed segments, working into a pinion upon the crank shaft of the engine. If the level of water in the

delivering drain and in the river does not vary much, one speed for the wheel is sufficient; but if the tide rises to any great extent, it is found desirable to have two speeds of wheel work, one to be used at low water, and the more powerful combination to act against the rising tide. It is usually not necessary to raise the water more than 3 or 4 ft. above the surface to be drained, and that only when the river is filled by long-continued rains or floods from the upland. If the main drains be 7½ ft. deep, and the floats dip 5 ft. below the surface of the water, 1 ft. in depth will be left below them to admit the passage of weeds or other matters, and the water will yet be kept 18 in. below the surface of the land. If the wheel dips 5 ft. below the drain-water level, and the level of the water in the river is 5 ft. above that in the drain, the wheel will be said to have "10 ft. head and dip," and should be 28 or 30 ft. in diameter. For a dip of 5 ft. and head of 10 ft., that is, "a head and dip of 15 ft.," Mr. Glynn used wheels of 35 ft. to 40 ft. in diameter. A wheel of 40 ft. diameter, and situated on the ten-mile bank near Littleport in the Isle of Ely, is driven by an engine of 80-horse power. The largest quantity of water discharged by one engine is from Deeping Fen, near Spalding. This fen comprises 25,000 acres, drained by two engines of 80 and 60-horse power. The 80-horse power engine works a wheel 28 ft. diameter, with float boards 5½ ft. by 5 ft., and moving with a mean velocity of 6 ft. per second. When the engine has its full dip, the section of the stream is 27½ ft., and the quantity discharged per second is 165 cubic feet, equal to more than 4½ tons. These two engines were erected in 1825, before which time the district had been kept in a half cultivated condition (being sometimes wholly under water) by 44 windmills.

The land now grows excellent wheat, producing (in 1848) from four to six quarters to the acre. In many districts land was purchased by persons who foresaw the consequences of these improvements, which they could now sell

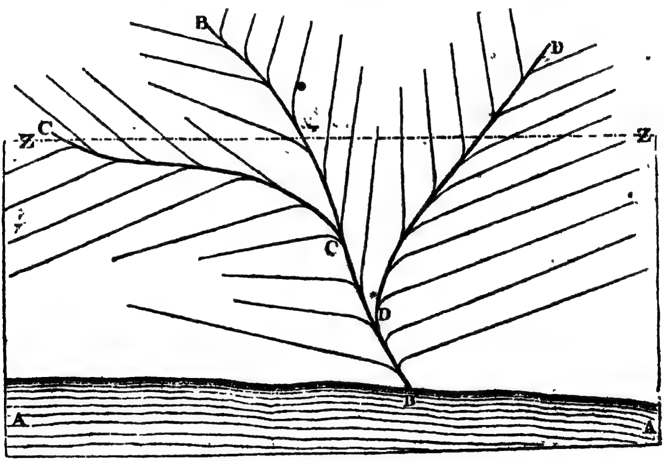
at from 50*l.* to 70*l.* per acre. This increase in value has arisen not only from the land being cleared from the injurious effects of the water upon it, but from the improved system of cultivation it has enabled the farmers to adopt. The fenlands in Cambridgeshire and great part of the neighbouring counties are formed of a rich black earth, consisting of decomposed vegetable matter, generally from 6 to 10 ft. thick, although in some places much thicker, resting upon a bed of blue gault containing clay, lime, and sand. When steam-drainage was first introduced, it was usual to part the land and burn it, then to sow rape-seed, and to feed sheep upon the green crop, after which wheat was sown. The wheat grown upon this land had a long weak straw, easily bent and broken, carrying ears of corn of small size, and having but a weak and uncertain hold by its root in the black soil. Latterly, however, chemistry having thrown greater light upon the operations of agriculture, it has been the practice to sink pits at regular distances through the black earth, and to bring up the blue gault, which is spread upon the surface as manure. The straw, by this means, taking up an additional quantity of silex, becomes firm, strong, and not so tall as formerly, carrying larger and heavier corn, and the mixture of clay gives a better hold to the root, rendering the crops less liable to be laid by the wind and rain, whilst the produce is most luxuriant and abundant. Mr. Glynn has applied steam-power to the drainage of land in fifteen districts, all in England, and chiefly in the counties of Cambridge, Lincoln, and Norfolk, to the extent of more than 125,000 acres, the engines employed being seventeen in number, of sizes varying from 20 to 80 horses, and having an aggregate power of 870 horses. The same engineer has also drained, by steam-power, the Hammerbrook district, near Hamburg, and designed the works for draining a level near Rotterdam, which have been carried out by the Chevalier Conrad.* In

* Abstract of a Report on the Application of Steam Power to the

British Guiana the steam engine has been made to answer the double purpose of drainage and irrigation. Some of the sugar plantations of Demerara are drained of the superfluous water during the rainy season and watered during the dry season.

101. Recurring to fig. 10, p. 62, the districts there illustrated will require methods of drainage determined by the inclination of the surface. If this be comparatively level, the drains may be generally cut with beds parallel, or nearly so, to the surface, and arranged to deliver into one or more main drains having lower beds, but still above the low-water level of the river or receiving channel, and from which the water can be let off when the tide is down by providing

Fig. 23.

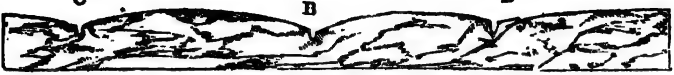


sluices suitable for the purpose. If the surface undulates, the main drains must be laid in the hollows, and the feeders be distributed over the higher parts, and made to communicate with the mains. Small sluices fixed at intervals,

Drainage of Marshes and Fen Lands, to the British Association for the Advancement of Science, 1848, by Joseph Glynn, F.R.S., M. Inst. C.E.

both in the main and minor drains, will, by intercepting the water, permit an accumulation when desired for flood-

Fig. 24.



ing or irrigating the higher lands. Figs. 23 and 24 show a plan and section of a district of this character. A A is the river or receiving channel; B B the principal main drain; and C C and D D two other main drains delivering into it; each of the mains receiving the drainage from the feeders or minor drains. Fig. 24 is a section supposed to be taken on the line Z Z on the plan. Two imperative rules require to be observed in these arrangements, viz. that all the junctions shall be curved, and that no two feeders shall enter the main drain at opposite points. If these rules are neglected, the currents will be interrupted at these points, and mischief may arise from flooding when the drains become filled in wet seasons. It is also advisable, if the ground be of a loose texture, to guard the junctions with a few rough stones piled together in the form of a retaining wall; or, for greater permanence, concreted with lime and gravel, as shown in the plan and sections, figs. 25, 26, and 27, of which fig. 25 is a plan, fig. 26 a section through the ordinary drain taken on the line Y Y; and fig. 27 a section through the guard-walls, taken on the line X X.

102. If the general inclination of the surface of the district be considerable, it is often desirable to form catch-water drains, or series of drains at different elevations, communicating with each lower one successively by falls. By this method great facilities are obtained for regulating the management of the waters, so that any required quantity can be retained to compensate for seasons of drought; while, moreover, the falls are applicable as water-power, and may be used for a variety of purposes. Fig. 28 is a

Fig. 25.

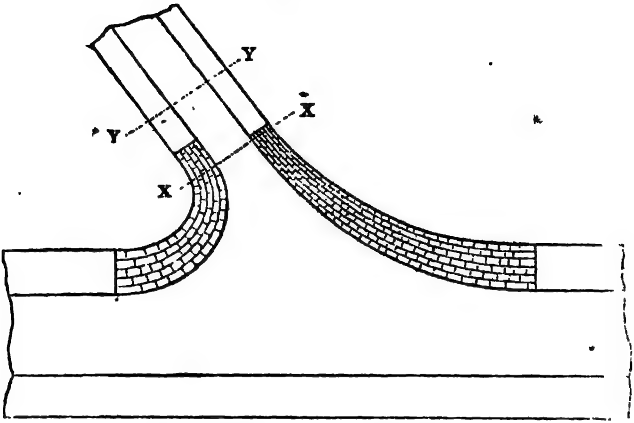


Fig. 26.

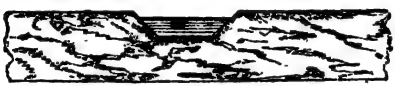


Fig. 27.

plan, and fig. 29 a section of a district drained in this manner. A A, B B, and C C, are the main or catch-water drains, each of which receives the drainage from the minor drains or feeders connected with it, and delivers it to the next lower main, through the channels *a a*, *b b*, and *c c*, each of which has sluices fitted to it, while the water forms a series of falls at the points marked *y*. Or the water from the superior levels may be received in reservoirs constructed for the purpose and in the places of the catch-water drains, and there disposed of for agricultural, manufacturing, or domestic purposes.

103. In fig. 11, p. 63, we have sketched an inland body

Fig. 28.

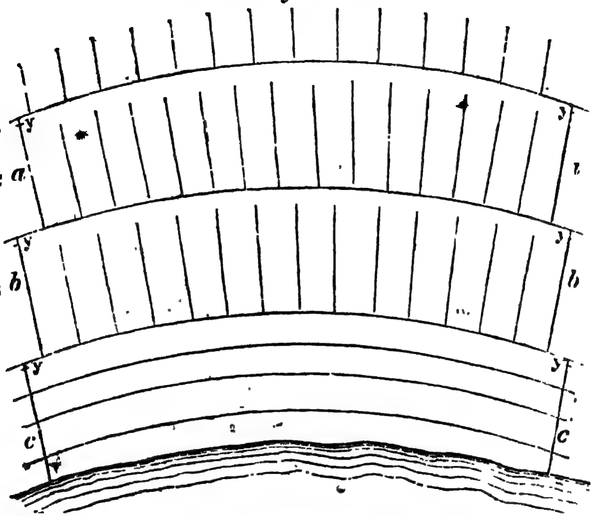
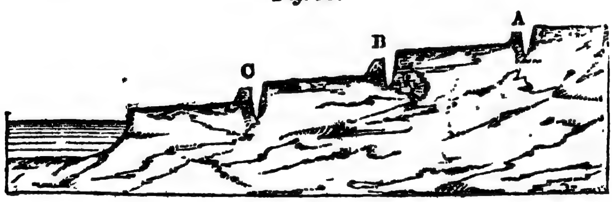


Fig. 29.



of water, or lake, which receives the drainage of the adjacent districts, and to these, thus situated, the same methods of draining as those just described are generally applicable. The formation of lakes upon the surface of our globe appears to have resulted from three causes, viz. the outcropping of internal springs or sources of water; subterranean communication with seas; or, the flowing down and accumulation of the surface waters from the surrounding and more elevated districts. Lakes formed by the first of these causes being constantly fed and replenished, may be re-

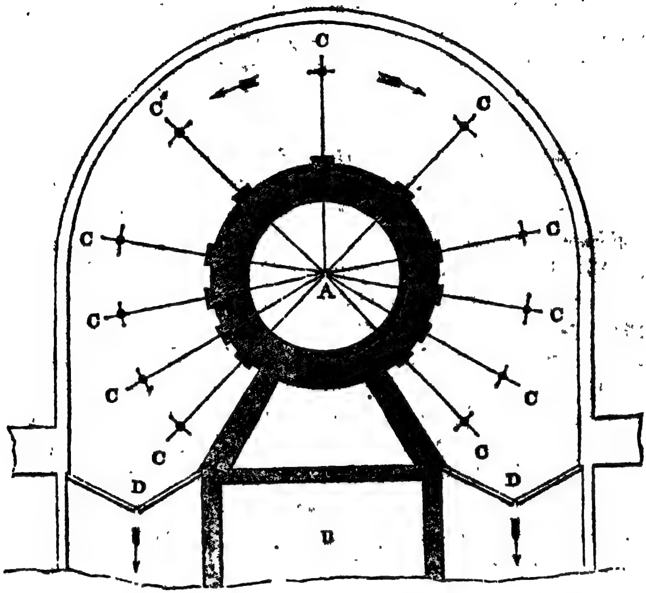
garded as permanent reservoirs; and those formed by the second are dependant upon the preservation of their inlet from the ocean; but those which receive their supply from the drainage of the lands around, appear destined to extinction by the constant deposit within them of the solid matters brought down by the water. Thus, the Black Sea, the Caspian, and Arral, are fairly supposed to have originally formed one vast lake, the ridges in which have now become elevated, so as to form permanent boundaries between them. The Caspian, also, has evidently become reduced in extent, as proved by the marine matters now found at a distance from its present shores.

104. Fresh-water lakes, of considerable extent and little depth, are sometimes worthy of being entirely drained for the sake of cultivating the site they occupy. One of the most recent examples of this class of works is the drainage of the Lake of Haarlem in Holland. This lake is situated between Leyden and Amsterdam, and communicates with the Zuyderzee. The bottom of it consists of a rich alluvial deposit well fitted for agriculture. A Dutch engineer, popularly known by the name of "Leeghwater," or "drier up of water," formed a project for draining this lake in 1623, and another proposal for the same object was brought forward at the end of the last century, when steam was first employed in draining; similar works having been already executed in the Beilm and Diem. The area of the Lake of Haarlem is equal to 45,230 acres, and its average depth about 14 ft., the cubic contents being equal to 800,000,000 of tons of water. One part of the lake is 13 ft. under the level of the tide. The longest side of it is parallel to the sea, and separated from it only by a very narrow strip of land. Observations, continued during a period of 91 years, show that the maximum quantity of rain which falls upon the lake amounts to 36,000,000 tons of water monthly. The Dutch Government having appointed a commission of engineers to report upon the best means of draining the lake, many proposals were sub-

mitted and examined, and it was ultimately determined to adopt the plan recommended by Messrs. Gibbs and Dean. These gentlemen employed three engines for the purpose of draining the lake, each being of great power, whereby the total current cost was much less than would be incurred by using a greater number of smaller engines. These three engines are named the "Leeghwater," the "Cruquius," and the "Van Lynden," after three celebrated men of these names, who had interested themselves in the draining of the lake.

105. Of these three engines the "Leeghwater" was first erected, with suitable houses and pumping machinery. The first step in this work was to construct an earthen dam of a semicircular form, inclosing about 1½ acre of the area of the lake, and adjoining its bank. The space inclosed by this dam was then cleared of water by a small steam engine, and the foundations for the houses and machinery commenced. These foundations consisted first of 1400 piles, which were driven to the depth of 40 ft., into a stratum of hard sand. Upon these piles, and at the depth of 21 ft. below the surface of the lake, a strong platform was laid, and upon this a wall, pierced with arches, was constructed, at the distance of 22 ft. from the intended position of the engine-house. Upon this wall a thick flooring of oak was laid, between the wall and the engine-house. The pumps rest upon the platform, beneath and opposite to the arches, and their heads pass through the floor just described, standing about 8 ft. above its level. Into the space left between the engine-house and outer wall, the water raised by the pumps was received and discharged from it on either side of the boiler-house, through sluice gates, into the canals conducting to the sea sluices. The general arrangement of the engine, boilers, pumps, and sluices, will be understood from Fig. 30, in which A represents the engine; B the boiler-house; C C, the pumps; and D D, the sluices through which the water was discharged. The engine has two steam cylinders, one within

Fig. 30.



the other, united at the bottom, but with a clear space of 1½ in. between them at the top under the cover, which is common to both. The large cylinder is 12 ft., and the small one 7 ft. in diameter. The small cylinder is fitted with a piston, and the large cylinder with an annular piston. These pistons are connected by one main piston rod (of the internal cylinder) 12 in. diameter, and four small rods (of the annular piston) 4½ in. diameter each, with a great cap or cross-head, having a circular body 9 ft. 6 in. diameter, and formed to receive the ends of the balance beams of the pumps. The *pumps* are eleven in number, and each of them 63 in. diameter, with a cast-iron balance beam turning upon a centre in the wall of the engine-house, one end of which is connected with the great cap of the engine, the other to the pump rod. Each pump rod is of wrought

iron, 3 in. diameter, and 16 ft. long, with an additional length of 14 ft. of patent chain cable attached to the pump piston. The steam and pump pistons have a *stroke* of 10 ft. in length; each pump is calculated to deliver 6·02 tons of water per stroke, or 68·22 tons for the eleven pumps. The quantity actually raised was found to be about 63 tons. The *action* of the engine is as follows:—The steam being admitted, the piston and great cap are thereby raised, and the pump pistons make their down stroke. At the top of the steam stroke a pause of one or two seconds is made, to enable the valves of the pump pistons to fall out, so that, on the down stroke of the steam piston, they may take their load of water without shock. In order to sustain the great cap and its dead weight during this interval, an *hydraulic apparatus* is brought into use, which consists of vertical cylinders, into which water is admitted, forcing upward two plunger poles which sustain the cap, the water being prevented from returning by spherical valves fitted at the lower part of the cylinders. The arrangement of the *two* steam cylinders is adopted in order to bring the load under immediate command, the varying character of which would otherwise require occasional alteration of the dead weight to overcome it, which would involve great delays and inconvenience. By the use of the two cylinders, the dead weight raised by the small piston did not usually exceed 85 tons, the extra power required being derived from the pressure of the return steam at the down stroke upon the annular piston. A skilful regulation of the expansion and pressure of steam in the small cylinder thus enables the engine-man to provide for all cases of difference of resistance without the delay of altering the dead weight. Respecting the *power* of the "Leeghwater," it appeared, from experiments conducted by a sub-committee of the Commission, that the engine would do a duty equal to raising 75,000,000 lbs., one foot high, by the consumption of 94 lbs. of good Welsh coal, and exerting a net effective force of 350-horse power. The lift being 13 ft.,

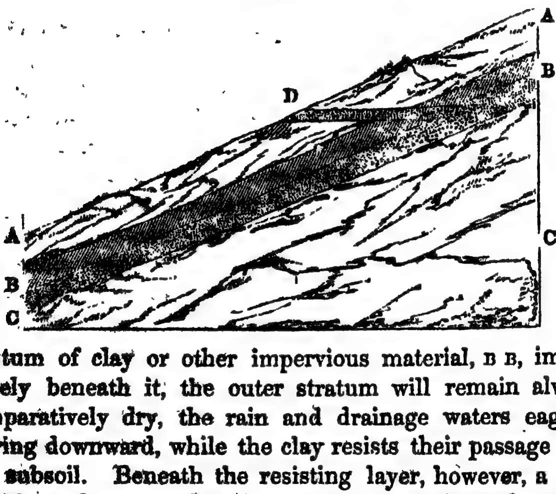
the engine worked the eleven pumps simultaneously; the net weight of water lifted being 81·7 tons, and the discharge 63 tons per stroke. When the site of the lake is cultivated, the surface of the water in the drains will be kept at 18 in. below the general level of the bed; but during floods the waters of the upper level of the country will be raised above their usual height, and the lift and head will be increased to 17 ft. To test the power of the engine to meet these cases, the eleven pumps were worked simultaneously, without regard to economy of fuel, and 109 tons net of water were raised, per stroke, to the height of 10 ft. The *boilers* of the Leeghwater engine are five in number, cylindrical, and each 30 ft. long, and 6 ft. in diameter, with a central fire tube 4 ft. in diameter. Under the boilers a return flue passes to the front, and then divides along the sides. Over the boilers, and communicating with all of them, is a steam chamber, 42 ft. in length, and 4 ft. 6 in. in diameter; from which a steam pipe, 2 ft. in diameter, conveys the steam to the engine. The *consumption of fuel* is $2\frac{1}{2}$ lbs. of coals per horse power per hour, when working with a net effect equal to the power of 350 horses. The *cost* of the "Leeghwater" and machinery was 21,000*l.*, and of the buildings and contingencies, 15,000*l.* It was calculated that the entire cost of the works for draining the lake would be 100,000*l.* less than would have been incurred by adopting the ordinary system of steam engines and hydraulic machinery, and 170,000*l.* less than the expense of applying the system of windmills hitherto prevailing in Dutch drainage. The *annual* cost of the three methods was thus estimated:—by three engines, such as the Leeghwater, 4500*l.*; by windmills, 6100*l.*; and by ordinary steam-engines, 10,000*l.*

106. The several methods of draining, as already explained in reference to figs. 9, 10, and 11, are also more or less applicable for districts of the kind sketched in fig. 12, and also for the second class, or Upper Districts. Thus, the drainage from the high lands has to be received and

collected in catch-water drains at the base of the hills, and means taken for combining these waters with those from the level district, or for keeping them separate, as may be required. Or reservoirs may be formed in connection with the catch-water drains, so that irrigation may not be necessarily suspended in cases of drought or deficiency of rain water.

107. Upland districts are liable (even with all the aid that can be rendered by economy of the natural supply) to suffer from an inadequate command of water. Thus, if, as shown in fig. 31, the surface of the district A A have a

Fig. 31.



stratum of clay or other impervious material, B B, immediately beneath it, the outer stratum will remain always comparatively dry, the rain and drainage waters eagerly flowing downward, while the clay resists their passage into the subsoil. Beneath the resisting layer, however, a permeable and saturated soil, as C C, is often situated, and in these cases an adit drain at D, or other convenient point, will bring the internal water to the surface, and probably aid the supply of the district with the drainage waters from a higher and overcharged level. Internal springs are also, in some cases, available for this purpose, and may be brought into use by simple and inexpensive means. If these resources fail, it may become desirable to apply me-

chanical power for raising the necessary quantity of water from a river or other reservoir at a lower level.

108. Various forms of apparatus have been devised and applied for the purpose of raising water, some of which are actuated by the accumulated force of small streams from superior levels; but these admit of very limited application for draining purposes. Pumping engines, worked by steam power, form the only class of machines at present available, by which the required accession of water can be, under all circumstances, brought up from the lower source. If the lower source, however, be a tidal river, the pumps may be worked by an undershot water-wheel placed upon it, and the water be delivered above into an artificial channel or aqueduct, and thence conducted to the higher levels.

109. A very extended and valuable experience of the powers of steam-pumping engines has been obtained in the mines of Cornwall, from the records of which a few facts may be usefully gleaned in this place as authentic data for application in many draining operations. The number of engines employed in these mines was, in 1822, 52, doing an average *duty* of 28,900,000. In the year 1843, 36 engines are reported, but their average *duty* had risen to 60,000,000. The *duty* is measured by the number of pounds weight of water raised 1 ft. high by the combustion of one bushel of coal. Thus, while in 1822, each bushel of coal raised less than 29,000,000 lbs. of water 1 ft. high, the same fuel was able, by improvements in the details of the engines, to raise 60,000,000 lbs. in 1843. The *best* engine in 1822 was a double cylinder one by Woolf, the *highest* duty of which was 47,200,000. The best engine in 1842 was a single cylinder (85 inches) engine, by Hocking and Loam, the highest duty of which was 107,500,000. This engine was erected in 1840, and was especially intended to work more expansively than had hitherto been practised. The boilers were made smaller in diameter than usual, and of stronger plate, so as to stand a

higher pressure of steam, the working elasticity being fixed at 40 lbs. per square inch above the atmosphere. Also an extra number of boilers was provided, in order to give an increased proportion of heating surface, and the strength of the working parts of the engine and machinery was augmented to withstand the strain caused by the great force of the steam on the piston at the commencement of the stroke. The progress of the application of the expansion principle has been intimately connected with the deepening of the shafts of mines. In order to render this principle effective in practice, to any great extent, it is necessary that a considerable load be moved by the engine-stroke. As the mines were deepened, the weight of the pump rods and balancing machinery necessary for draining them was of necessity increased; thus furnishing the load required, and affording at once occasion and opportunity for gradually extending the improvement derivable from the principle of expansion.

110. Motive power may frequently be obtained from streams of drainage water collected or received from superior levels, and economically applicable to pumping and the actuating of mills and other agricultural machinery.*

* As an example of the adaptation of water power derivable from drainage to agricultural purposes, the arrangement adopted upon the estate of Lord Hatherton, in Staffordshire, may be aptly adduced. "His lordship has there had collected very cleverly the drainage water of the higher lands of his estate; he has erected several ponds for storing it, and he has it carried to his farm-yard, where it drives a powerful water-wheel, which does all the thrashing, milling, chopping, &c., and drives a saw-mill besides. From the mill the water is carried in canals of gentle fall to lower meadow ground, where it is used in extensive and profitable irrigation. Drain-water always contains more or less of the manure and soluble parts of the soil in suspension; and the fertilising properties of the drain-water on this estate are particularly marked by the very luxuriant growth of grass it produces on the meadows. This experiment forms a noble example of an economy in agriculture worthy of imitation, and is one which can be carried out to a greater or less extent on all farms having surfaces at different altitudes."—*Answer by the late James Smith, Esq., of Deanston, to Query No. 13, issued by the Metropolitan Sanitary Commissioners.*

Machines which derive their motive force from water are constituted mainly of a wheel or revolving lever apparatus, actuated either from the circumference or from the centre. In the former case, the wheel is usually made to revolve vertically upon an horizontal axis, and receives the impulse afforded by the weight and motion of the water at a level above the periphery of the wheel, or just below the axis, or identical with the lowest position which the periphery assumes in the course of its rotation. The wheels are distinguished in each of these arrangements respectively, as *overshot, breast,* and *undershot.* Water-wheels actuated from the centre derive their motion from the resistance offered by arms or vanes to the *centrifugal* disposition of the water, which thus *reacts* and produces a rotatory motion in the opposite direction. They are thus commonly known as "*reaction water-wheels,*" and in France have received the name of "*turbine,* or *horizontal water-wheel,*" from the position of the wheel, the axis being *vertical.* The celebrated French experimenters, Poncelet and Morin, have ascertained that overshot wheels and turbines produce an effect equal to from 60 to 80 per cent. of the power exerted; that breast-wheels produce from 45 to 50 per cent; and that undershot-wheels produce only from 27 to 30 per cent., being thus the least effective of all.

111. As the inventor of turbines, M. Fourneyron has attained considerable celebrity in France, and is reported to have realised an useful effect equal to 87 per cent. of the power expended. The proportion of effect to power is, however, not the only criterion of the usefulness or adaptability of these machines. Many circumstances are usually present which will dictate, or enable us to arrive at, a selection of such an apparatus as will be practically found to yield ample useful effect. Thus M. Fourneyron has produced a good average effect from a simple apparatus, with a *fall of water of only nine inches.* There are many places, especially in hilly districts, where high falls of water are found, and where the nature of the ground affords facilities

for making reservoirs, so as to insure a constant supply, where the height of the column of water may compensate for the smallness of its volume. And there are other situations where a great volume of water rolls with a very trifling fall. In either of these cases the turbine may be applied with great advantage. It, moreover, occupies a very small space in comparison with a water-wheel of the same power; its speed is high, and the expense of its construction greatly below that of any other effectual mechanism for deriving a rotatory motion from a head of water.

112. The turbine of M. Fourneyron consists of a horizontal water-wheel, in the centre of which the water enters; diverging from the centre in every direction, it enters all the buckets at once, and escapes at the circumference or external periphery of the wheel. The water acts on the buckets of the revolving wheel with a pressure in proportion to the vertical column or height of the fall; and it is led or directed into these buckets by stationary guide curves, placed upon and secured to a fixed platform within the circle of the revolving part of the machine. The efflux of tho water is regulated by a hollow cylindrical sluice, to which a number of stops, acting simultaneously between the guide curves, are fixed. With this short cylinder, or hoop, they are all raised or lowered together by means of screws communicating with a regulator or governor, so that the opening of the sluice and stops may be increased or diminished in proportion as the velocity of the wheel may require to be accelerated or retarded. This cylindrical sluice alone might serve to regulate the efflux of the water, but the stops serve to steady and support the guide curves and prevent tremor.

113. One of these machines, erected by M. Fourneyron for M. Caron, was of 50-horse power, the fall of water being 4 ft. 3 in., and the useful effect varied with the head and the immersion of the turbine from 65 to 80 per cent. Another erected at Inval, near Gisors, for a fall of 6 ft. 6 in., the power being nearly 40 horses, expended 35 cubic

feet of water per second, and produced an useful effect of 71 per cent. of the force employed. One with a fall of 68 ft. gave 75 per cent.; and when it had the full height of column for which it was constructed, viz. 79 feet, its useful effect is said to have reached 87 per cent. of the power expended. Another, with 126 ft. fall, gave 81 per cent., and one with 144 ft. gave 80 per cent. In 1837, M. Fourneyron erected a turbine at St. Blasier, in the Black Forest of Baden, for a fall of 72 ft. The wheel is made of cast iron, with wrought-iron buckets; it is about 20 in. in diameter, and weighs about 105 lbs.; it is said to be equal to 56-horse power, and to give an useful effect equal to 70 or 75 per cent. of the water power expended.

114. The turbine is adapted, when applied to tidal waters, to work with one flow only; and to improve on this arrangement, and produce a continuous movement both with the rise and fall of the tide, is the object aimed at in Mr. Gwynne's "Double-Acting Balanced Pressure Wheel," which is said by the inventor to effect a saving of from 33 to 50 per cent. on the first cost (as compared, it is presumed, with the ordinary water-wheels), to produce an useful result equal to 85 per cent. of the power employed, and to maintain a perfect operation irrespective of floods or large accumulations of back water. This contrivance consists mainly of a flat cylindrical casing, with a vertical spindle passing through its centre, and carrying the internal wheel or arrangement of buckets which receive the impulse of the water entering at the periphery, the peculiar feature of the invention consisting in the shape of the partitions or buckets, which are adapted to present a direct surface to the action of the water in its passage through, whether it passes in one direction or the reverse of it.

115. Dr. Barker's mill, which was formerly neglected as being useless for practical purposes, is now recognised as involving important principles of action. It consists of a vertical tube, terminating in an open funnel at top, but closed at the lower end, from which project, at right angles

two horizontal tubes in opposite directions, in communication with the vertical tube, and having closed outer ends. Each of these horizontal arms, however, has a round hole on one side of it (the two holes being opposite to each other), and the vertical tube being mounted on a spindle or axis is kept full of water flowing into the top. The issue of the water from the holes on opposite sides of the horizontal arms causes the machine to revolve rapidly on its axis, with a velocity nearly equal to that of the effluent water, and with a force proportionate to the hydrostatic pressure given by the vertical column, and to the area of the apertures; for there is no solid surface at the apertures to receive the lateral pressure, which acts with full force on the opposite side of the arm. According to the celebrated Dr. Robison, this unbalanced pressure is equal to the weight of a column, having the orifice for its base, and twice the depth under the surafce of the water in the trunk for its height. Desaguliers, Euler, John Bernoulli, and M. Mathen de la Cour, have treated of this machine, and the last-named author proposed (in 1775) an arrangement by which any fall or column of water, however great its height, may be rendered available. This proposition was to bring down a large pipe from an elevated reservoir, to bend the lower part of it upwards, and to introduce into it a short pipe with two arms, like Dr. Barker's mill reversed, and revolving on an upright spindle in the same manner; the joint of the two pipes being so contrived as to admit of a free circular motion without much loss of water.

116. In the year 1841, Mr. Whitelaw essayed an improvement of this machine, and obtained a patent for it. This contrivance appears to consist mainly in the modifications suggested by Dr. Robison and M. Mathon de la Cour, and in the bending of the two horizontal arms into a form resembling that of the letter S. In this machine, the water is discharged from the ends of the arm in the direction of the circle described by their revolution, or in that of a tangent to it, the capacity of the arms increasing as they

approach the centre of rotation, so as to contain a quantity of water at every section of the arm inversely proportionate to its velocity at that section, with the view of economising the centrifugal force. The transverse sections of the arms are everywhere parallelograms of equal depth, but of width increasing from the jet at the outer extremity of the arm to the central vertical pipe. In a model of this form, with a fall of 10 ft., the diameter of the circle described by the ends of the arms being 15 in., and the aperture of each jet 2·4 in. in depth, by ·6 in. in width (the area of each orifice being thus 1·44 in.), the water expended was 38 cubic feet, the velocity 387 revolutions per minute, and the effect equal to 73·6 per cent. of the power employed.

117. Mr. J. S. Gwynne publicly exhibited, at the *Passaic Copper Mine*, U.S., in January, 1849, his "direct acting balanced pressure centrifugal pump," and obtained patents for the invention in the United States, 1850, and in England in March, 1851. The "balanced centrifugal pump," as described by the patentee, has a rotatory action, by which a centrifugal movement is given to the inclosed water, which it discharges in radial lines coincident with the direction of the centrifugal force, into a flattened spheroidal chamber, constituting the body of the pump, and having but one exit pipe, placed at a tangent with its circumference. The water, as it is thrown off from the open periphery of the revolving piston, is forced up the discharge-pipe in quantities, and at a rate, proportioned to the speed at which the piston is driven. The piston is formed of two concave discs placed parallel, with their concave surfaces towards each other. Between these discs is a single arm, or impeller, radiating from a boss, or hollow axis, mounted on a shaft, which may work horizontally, vertically, or obliquely. The impeller varies in breadth; its narrowest part is at the outer edge of the piston, and it becomes gradually broader, until its edge intersects the inner surface of the opening in the suction side of the piston, from which line, to its extremity at the boss, its

edges continue parallel to each other, and at right angles to the axis of the shaft. In working the pump, the water is poured into the piston, at its centre, through a circular opening in one of its sides and concentric with it. The piston is inclosed in a case placed parallel and concentrically with the discs, and which acts as a receiver. From the circumference of this case, and at a tangent to it, the discharge-pipe rises perpendicularly. To prevent the water rotating in the case, and to give it a direction upward to the discharge-pipe, a stop or plate is provided. The joint between the suction pipe and piston is carefully made, and so situated, that no sand, gravel, or other gritty matter can lodge in or near it. Mr. Gwynne also describes a "balancing nut," and claims that or any other contrivance for "equalising the lateral pressure on the piston, which would give rise to very serious inconveniences in the use of the pump, when great elevations of water were to be obtained; for, in raising it to great heights, the pressure would be excessive, amounting to many tons." As applicable to works of drainage and irrigation, the patentee announces the sizes, powers, and prices of his pumps as follows:—

Size of Pipes.		Gallons of Water raised 30 ft.	Equal to Horses' Power.	No. of revolutions per minute of Piston required to raise Water.				Price.
Discharge.	Suction.			10 ft.	20 ft.	30 ft.	60 ft.	
in.	in.							£
6	7	1320	15	500	700	800	1200	40
9	10	3000	35	375	525	600	900	85
12	13	5310	60	250	350	400	600	200
18	20	12000	136	171½	240	275	412½	437
24	26	21000	240	125	175	200	300	750

118. In November, 1848, Mr. Appold exhibited a model of a rotatory pump as a convenient one for draining purposes, and made experiments on it with 6, 24, and 48 arms or vanes. A pump of this description was shown at the Great Exhibition of 1851, and experimented upon by the jury. In this pump the fan revolving vertically was 1 ft. diameter, and 3 in. wide, having an opening one-half the total

diameter in the centre of each side for the admission of the water, and a central division plate extending to the circumference, to give a direction to the two streams of water, and convenient for fixing on the shaft; the 6 arms curved backwards, terminating nearly tangential to the circumference. The revolving fan was fixed on the end of the horizontal driving shaft, passing through a stuffing-box in the side of the casing, and it worked between two circular cheeks, running close without actually touching, by which the outer revolving surfaces were shielded from the water, but a free ingress allowed for the water, and a large space left all round the periphery of the fan, facilitated the discharge of the water. In the experiments instituted by the jury, the power employed was measured with great care by means of Morin's dynamometer, and the following results obtained:—

Appold's Centrifugal Pump, with Curved Arms.

Height of Lift.	Discharge per Minute.	Revolutions per Minute.	Velocity of circumference.	Percentage of effect to Power.
ft.	gallons.		ft. per minute.	
8·2	2100	828	2601	59
9·0	1664	620	1948	65
18·8	1164	792	2988	65
19·4	1236	788	2476	68
27·6	681	876	2751	46
With Straight Inclined Arms.				
18·0	736	690	2168	43
With Straight Radial Arms.				
18·0	474	720	2262	24

A large pump constructed on this plan erected at Whittlesea Mere, for the purpose of draining, was reported, in July, 1852, to have been then working for nearly a year

with complete success. This pump is 4½ ft. diameter, with an average velocity of 90 revolutions, or 1250 ft. per minute, and is driven by a double cylinder steam engine, with steam 40 lbs. per inch, and vacuum 13½ lbs. per inch; it raises about 15,000 gallons of water per minute, an average height of 4 or 5 ft. The cost of the engine and pump was about 1600*l.* The following experiments were tried to ascertain the percentage of effect obtained from the pump; the power employed being measured by taking indicator figures from the engine, deducting in each case the power that was indicated when the engine was working at the same speed without the pump, which was found to take 10·6-horse power. The quantity of water discharged was measured by calculating the overflow from an opening 6 ft. wide in each case.

	Experiment First.	Experiment Second.	Experiment Third.	Experiment Fourth.
Velocity of circumference of pump, in feet, per minute...	1159	1357	1301	1329
Height of lift, in feet and inches	3 0	4 1	5 0	5 11
Depth of water at points of overflow, in feet and inches, A.	1 4	1 5¼	1 3⅜	1·2
Ditto, at 17 ft. distance, B. ...	1 7	1 8½	1 6⅝	1·5
Gallons discharged per minute, according to the depth, A.	12,429	14,223	11,706	95,45
Ditto, ditto B.	16,104	18,023	15,288	13,606
Theoretical discharge	17,400	21,587	15,768	12,803
Horse power effective in raising the quantity, A.	11·34	16·88	17·79	17·17
Ditto ditto B.	14·70	22·38	23·24	24·49
Horse power employed in working the pump	23·00	40·90	29·90	39·80
Percentage of effect to power employed, by calculation, A.	49	41	60	43
Ditto ditto B.	64	55	78	61

The centrifugal pump has been found more advantageous

for lifts below 20 ft. than for higher lifts, and its most advantageous application is as a tidal pump, where the height of lift is continually varying, because the lower the lift, the greater is the discharge, the speed of the pump remaining the same. This form of pump has also been applied with advantage as an assistant or feeder to a water-wheel, to keep the latter going constantly in the summer time, when short of water.

SECTION III.

Means of Conveying, Distributing, and Discharging Water.—Drains and Watercourses.—Forms, Sizes, and Methods of Construction.—Implements employed.—Shallow and Deep Draining.—Stone, Tile, and Earthenware Drains, &c.

119. Having in the preceding sections shown the general principles of draining, as applicable according to the general profile of the district, we have now to direct our attention to the details of the system; to show the methods to be selected with reference to the nature of the soil and the position of the substrata, and to consider the arrangement, form, size, and construction of the drains which it may be necessary to provide in order to promote the objects of agriculture.

120. The *nature* of the several soils which we have to deal with will be best understood by regarding the manner in which they have been formed, and the several materials of which they are constituted. The formation of all soils may be very clearly traced to the disintegration, by mechanical and chemical agencies, of rocks and minerals which contain alkalies and alkaline earths. In the mountainous districts of perpetual snow, the most refractory rocks are crumbled into fragments, which, being rounded by the action of glaciers, or pulverised into dust, are borne down by the rivers and streams, and deposited upon the plains and valleys below. Some of the most remarkable proofs of the influence of the air, water, and carbonic acid upon

the constituents of rocks, are exhibited in parts of South America, where the elements of the silver ores are gradually dissolved and dissipated by the action of these agents in the winds and rains, and the metal, resisting the destruction, is left exposed in sharp angular projections from the surface of the rock.*

121. The yellow clay which occurs so frequently in Denmark is considered by Forchammer to have been formed from granite, the felspar of which has undergone change, while the mica has not; the quartz forming the sand of the clay. The blue clays, having no mica, appear to have been formed from sienite and greenstone. The great stratum of clay which occurs at Halle has resulted from the disintegration of porphyry. Most of the sandstones contain silicates with alkaline bases, and in the sandstone of the Holy Mountain, near Heidelberg, fragments of felspar are observed partly changed into clay, and visible at white points in the sandstone. Felspar is unable to resist the solvent action of water when saturated with carbonic acid. Clays formed by the disintegration of felspars containing potash are free from lime; those formed from Labrador spar, which is the principal component of lava and basalt, contain lime and soda. Most rocks, as felspar, basalt, clay, slate, porphyry, and the numerous varieties of the limestone formation, consist of compounds of silica with alumina, lime, potash, soda, iron, and protoxide of manganese; and from the fact that most of these ingredients are susceptible of uniting with oxygen, the cause of the disintegration of the rocks which they constitute may be readily and fairly inferred. Of these constituents, the protoxide of iron has a great disposition to absorb oxygen from the atmosphere; thus forming the higher oxide or peroxide of iron. This property is indicated by the reddish brown colour of the rich ferruginous soils, while the black colour of the subsoil shows the presence of the protoxide. In the process of subsoil-ploughing, this protoxide frequently be-

* Darwin, Liebig, &c.

comes exposed, and the consequence is, that the fertility is impaired until the protoxide is converted into peroxide, and the red colour becomes apparent upon the surface. Struve has proved by experiments, that water which is impregnated with carbonic acid decomposes all rocks containing alkalies, and then dissolves a portion of the alkaline carbonates.

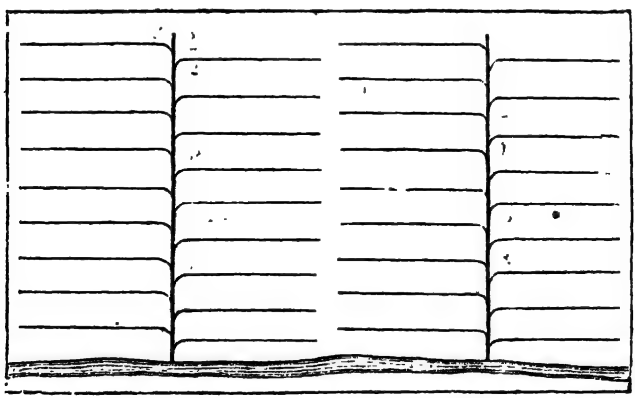
122. Soils being thus *formed* by the disintegration of rocks, their *properties* are evidently dependent, first, upon the nature of the several components of these rocks; and, secondly, upon the effects produced upon these components by the action of the air and water to which they are subsequently exposed. Of the various kinds of soil, the principal constituents are—1. *sand*, 2. *lime*, and 3. *clay*. The first two of these, containing no other inorganic substances except siliceous earth and carbonate or silicate of lime, afford no nutriment whatever for vegetation. The clay or argillaceous earth constitutes the fructifying element in all soils, and is produced by the disintegration of aluminous minerals, among which are the felspars, mica, &c. The fertilising properties of argillaceous earths appear to arise from their containing alkalies and alkaline earths, with sulphates and phosphates, ingredients which are never absent from these earths. This valuable property of the argillaceous earths is also aided by the peculiarity of their texture, which affords great facilities for retaining moisture. Vegetable life, however, requires, besides the nourishing properties found in the argillaceous earths, to be supplied with air and moisture, and while alumina gives no aid to the passage of these essentials, chalk and sand do give it by their mechanical formation. Hence, "land of the greatest fertility contains argillaceous earth and other disintegrated minerals, with chalk and sand in such a proportion as to give free access to air and moisture."* The *clays* are therefore to be regarded by the drainer as *impermeable* and *retentive* materials, and the *sands* and *limes* as *porous* ma-

* Liebig.

terials; and the infinitely varied proportions in which these matters are found combined in soils, determine the degree in which each soil will facilitate or impede the passage of water through it.

123. With this knowledge of soils, we may proceed to the *arrangement* of the drains required for regulating the supply of water to the lands of a district. This arrangement will be varied according to the contour of the surface, and the position of the substrata. If this be level, and the texture of the soil uniform, the drains may be at once planned, with mains at certain intervals, and minor drains or feeders at right angles to the mains, and parallel among themselves, as shown in fig. 32. The inclination in the

Fig. 32.

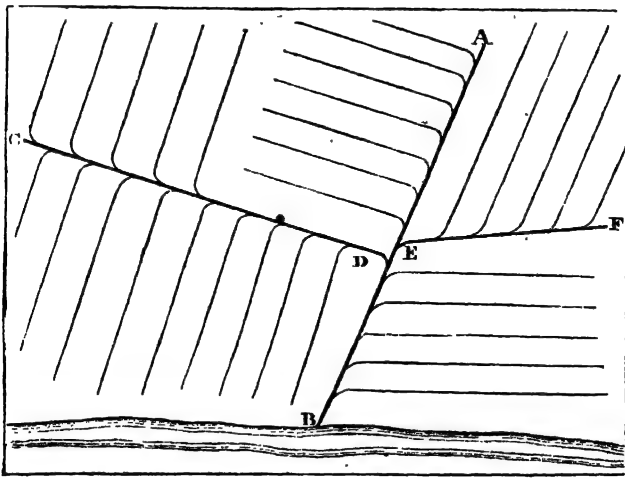


bed of the drains, which is necessary to assist the discharge of their contents, must be obtained by cutting them deeper towards the receiving channel, as shown in fig. 33, which is a longitudinal section of one of the main drains, with the feeders discharging into it. This increase of depth also provides the additional capacity wanted in the drains as the water accumulates in them. An undulating surface will require the main drains to be arranged at the lowest

Fig. 33.

levels, and the minor channels conducted into them with due reference to the capacity of the mains to discharge their united contents. Fig. 34 is a plan of a surface of

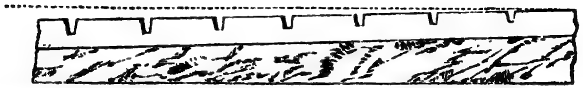
Fig. 34.



this kind, the lines A B, C D, and E F, showing the position of the hollows in which the main drains are to be laid, the minor ones being arranged so as to divide the total discharge among the mains as nearly equally as the nature of the surface will conveniently admit. The capacity of the mains, as also of the feeders, must, of course, be determined according to the quantity of water for which passage is required, and modified also by the steepness of the fall. If the fall is considerable, a drain of smaller dimensions will suffice than will be necessary if but little inclination

can be obtained. That part of the main drain from E to B will, in any case, require enlarged capacity, as it receives the entire drainage. Fig. 35 is a section of part of the

Fig. 35.



mains, in which it will be seen that, as the surface inclines, the bed of the drain will have sufficient fall if laid at equal depth from the surface of the ground throughout. The drains are arranged parallel to each other, which is evidently a good rule where it can be observed, the surface being thus divided into equal spaces, and the drainage made at once perfect and simple.

124. The arrangements of drains here described suppose the texture of the soil to be the same throughout the surface to be drained; but if soils of different retentive power appear upon the surface, it becomes essential to arrange the drains with reference to the line of junction of the soils. Thus, let figs. 36 and 37 represent the plan and

Fig. 36.

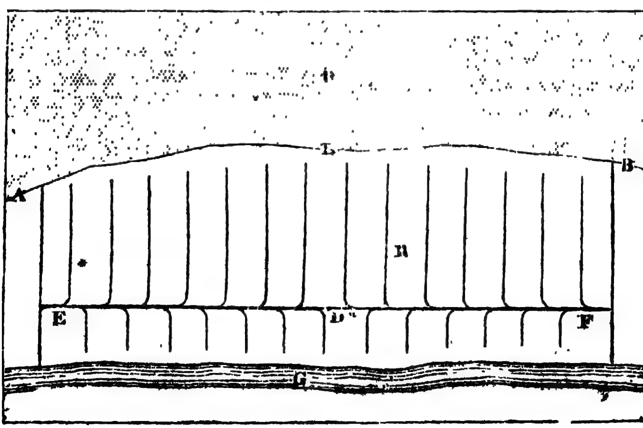
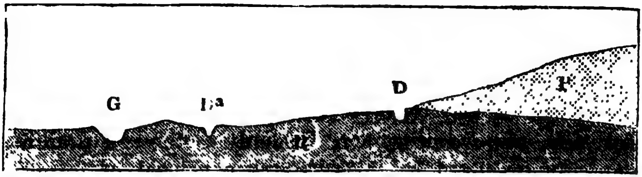


Fig. 37.



section of a district, whereof the higher ground is of porous materials, P overlying the clay, or other retentive soil (marked R), as far as the line A, D, B, where the clay first appears upon the surface. The water, percolating through the bed P, and prevented from descending by the clay, will accumulate along the line A, D, B, and form a swamp unless got rid of. In this case, therefore, a drain must be laid along this line, while a main drain for the remainder of the ground, which slopes towards the brook at G, must be formed on the line E, D^a, F. This latter drain receives the contents of the minor drains, which are to be laid parallel, as shown in fig. 36. The upper drain, A, D, B, discharges into the brook G by the cross ducts A E and B F. The two main drains must, if the surface permit it, be laid with their beds dipping either way from the middle at D and D^a, so as to insure the free passage of the drainage water.

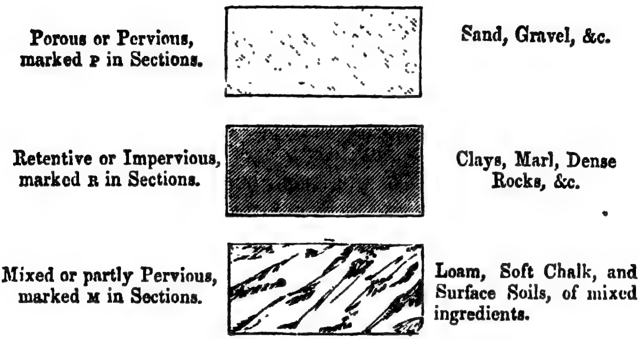
125. The general arrangement of the drains being, as already stated, controlled by the superficial contour and texture of the soil, cannot be properly determined without a careful reference to the sectional strata of the district. If these consist of materials of various degrees of porosity, their relative positions, not only on the surface, wherever the substrata may outcrop, but also in the section, must be regarded. In this kind of consideration consists one great field in which so much improvement *has been* already effected, and so much more *may be*, in the practical art of land-draining. The history of the art, indeed, informs us that the Romans consulted the nature of the soil in selecting the form of their drains; that they provided for drain-

ing from springs and subterranean sources as well as from the surface; and that they were thoroughly conversant with the superiority of covered and deep drains in certain circumstances. Without attempting to pursue this history, however, which is abundantly interesting, but far beyond our space, we may recall to the minds of our readers the fact that, some century ago, the only method of draining generally practised in this country consisted of forming the surface into rude ridges and furrows, and cutting open trenches by the hedges to carry off some of the superabundant moisture. But, more than this, we are called upon to attest the fearful truth, that our own little island still contains thousands upon thousands of acres of land in this same disgraceful condition, which are commonly condemned as *bad* lands, and regarded as evidences of the misfortunes, instead of the ignorance, of their cultivators. The modern art is not yet a century old. It appears to date principally from the methods instituted in the year 1764 by one Mr. Joseph Elkington, a Warwickshire farmer, who happening to drive an auger through the bed of a trench, discovered the existence of a water-bearing stratum beneath, by drawing the water from which, the surface and supersoil became thoroughly drained. The late Mr. Smith, of Deanston, and others, subsequently extended the principle of consulting the texture of the subsoils, and have adapted the depth, capacity, and construction of drains to these varieties of texture.*

* As early as the time of the Commonwealth, *deep draining* was advocated by Captain Walter Blith, who says—"Wherever you see drayning and trenching, you shall rarely finde few or none of them wrought to the bottome. But for these common and many trenches, ofttimes crooked too, that men usually make in their boggy grounds, some one foot, some two, I say away with them as a great piece of folly, lost labour and spoyle. And for thy drayning trench it must be made so deepe that it go to the bottome of the cold spewing moyst water that feeds the flagg and rush—a yard or 4 feet deepe if ever thou wilt drain to any purpose." And "to the bottome where the spewing spring lyeth thou must go, and one spade's graft beneath, how deepe soever it be, if thou wilt drain thy land to purpose."

126. Proceeding to examine the several varieties of the structure of soils which are met with, we propose to consider the strata under three leading characters, as exhibited in the following diagram, viz. the *porous*, or readily permeable; the *retentive*, or comparatively impervious; and the *semi-porous*, or mixed.

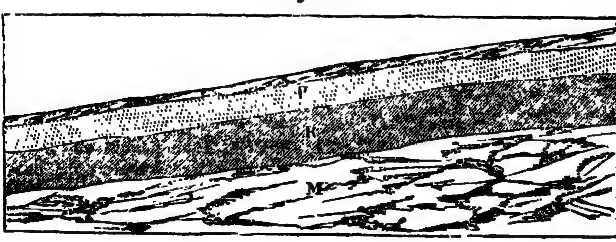
Characters of Strata.



This diagram, therefore, will serve as an index to the several sequent illustrations, numbered from 38 to 51 inclusive.

127. In fig. 38 we have a common arrangement of strata,

Fig. 38.

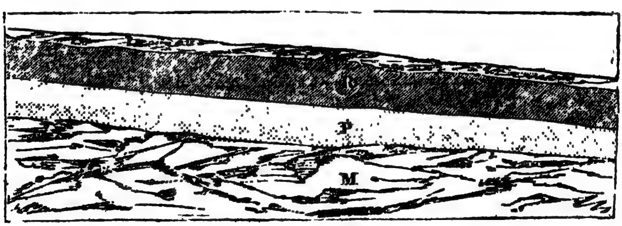


the surface-soil (which for its thinness need not be regarded), on a porous stratum, and this lying upon a retentive one. The method to be adopted, in this case, will

partly depend upon the thickness of the several strata. The water falling upon the surface will saturate the super-soil, and, being impeded by the lower stratum, will not pass away except by frequent drains, arranged with regard to the inclinations of the surface. If the clay beneath be of considerable thickness, so that the average depth of its bed from the surface exceeds 5 ft., it will be economical to limit the depth of the drains to the upper stratum, and thus avoid interference with the clay. The land, however, will be brought into a drier condition by penetrating the clay with the main drains at least. But, by doing so, if springs exist below the clay, they may thus become exposed, and the work of draining thereby augmented. Borings should, therefore, be made along the lines of lowest surface, and especially at any points where wet appears to gather, and, if any springs are thus detected immediately below the clay, they should be *tapped*, that is, have communications opened to the drain, so that their contents may pass away through the proper channels.

128. When the porous bed is beneath the clay or retentive bed, as shown in fig. 39, it will be advisable to cut the

Fig. 39.

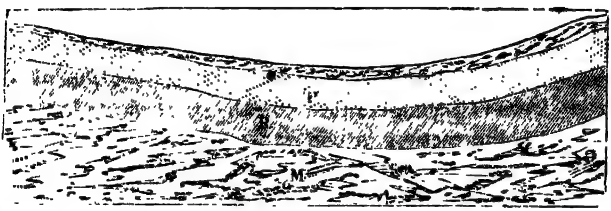


drains through the clay into the lower stratum, provided the latter is of sufficient depth to bear the water, and assist the drainage of the district. Supposing the entire depth of the lower bed from the surface does not exceed 6 ft., and it be desirable to economise the water for subsequent irrigation, or other purposes, it will be well to cut the drains

completely through both strata, and thus clear off the whole of the subwater, as well as that from the immediate surface. This arrangement of strata requires the drains to be laid at small intervals, and of ample capacity, as the dense super-soil will keep all the water which falls upon it, and also that which reaches it from superior levels. Some beds of clay are of such thickness that no practicable drains can be made to communicate with the substrata. When this is the case, the general system of drainage should consist of small drains laid very closely, so that the worked mass of clay may become thoroughly freed from an excess of water.

129. Fig. 40 represents a similar succession of strata to

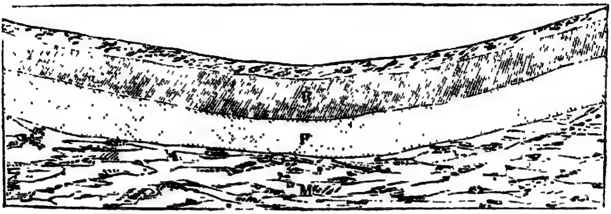
Fig. 40.



those shown in fig. 38, viz. the surface-soil resting upon a porous bed, and this upon one of a retentive character. But the contour of the surface is such, that the main drains must be formed in the middle of the section, which is the lowest part in the case here illustrated. The substratum of clay, rejecting the water, assists its accumulation at the point marked P, and it will become necessary to provide a drain of large dimensions in proportion to the extent of the district to be served. If the general surface is favourable, it will be better to arrange the principal number and extent of drains at right angles to the section, as here shown, rather than parallel with it. The main central drain will be thus relieved of the violence of the rapid discharges which the steep drains would send into it, and less danger will accrue from floods descending from the higher lands.

130. An arrangement of strata, which is very apt to discover springs rising to the surface, is shown in fig. 41, in

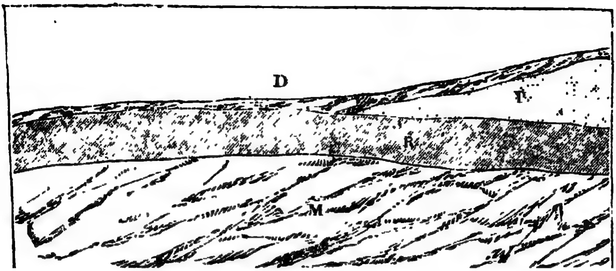
Fig. 41.



which the district appears to have a concave surface, with the porous stratum occupying the lower position. The water contained in the higher portions of this bed will burst forth at any outlets that may be formed through the clay; and indeed, if the latter be not of great depth, it will frequently force passages for itself, and thus augment the lower surface accumulations, which are collected at the middle of the section in consequence of its form, and the density of the upper clay. Efficient drainage will, in this case, require that the channels intersect the porous stratum, and, if the depth be not too great, the beds of the drains should reach that of the stratum. The position of the drains on the plan should also be determined, with a view to cut off the water from the gravelly bed at the higher parts of the section, and thus relieve the central main drain at R, which would otherwise become overloaded Three main drains, therefore, or more, if the sides of the basin be of great extent, should be laid, viz. one at the middle of the section, and two at the higher part, on either side of, and parallel with it.

131. In fig. 42, the strata are represented in positions which produce swamps or morasses. Thus, at the point D, at the foot of a porous bed, lying upon one of clay, which rises from that point, the accumulation of water will require a main drain to be laid, bounding the base of the

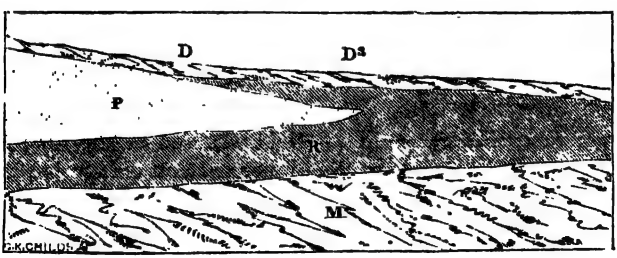
Fig. 42.



permeable stratum throughout the entire district, and to have a capacity in proportion to the extent of that stratum. If the clay be of inconsiderable thickness, the main drains should intersect it completely. In this arrangement it will be manifestly useless to cut channels *above* the point D, except as shallow feeders to the mains. This section illustrates one of the reasons of the failure of the methods formerly adopted of attempted drainage without consulting the structural condition of the soil.

132. Sometimes a tongue of gravel, or other pervious material, will be found to extend into and under the clay, as shown in fig. 43, in which a main drain at D, whatever

Fig. 43.

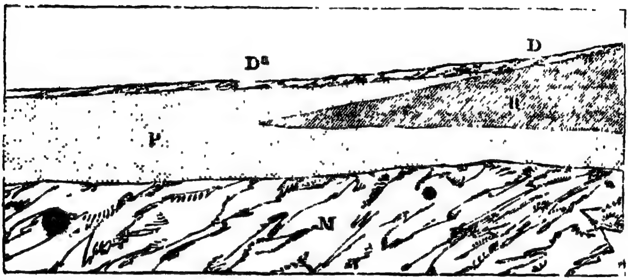


its dimensions may be, will not be sufficient to intercept the drainage water which passes through the bed, and will require another main at D². In this case, indeed, the prin-

cipal drain should be laid at this point; otherwise, that portion of the district lying between D and D[a] will remain in a moist and swampy state.

133. If, however, the position of the strata be reversed, and the clay runs into and beneath the porous material, as represented in fig. 44, the main drain at D should, if prac-

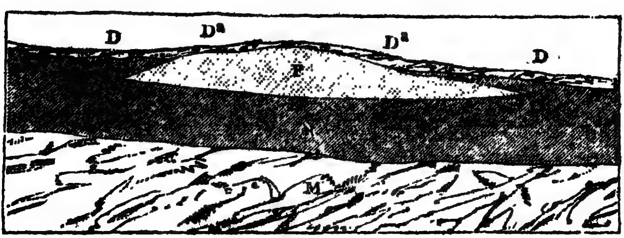
Fig. 44.



ticable, be cut through the clay, so that the water may be assisted in draining from it, and keeping the space from D to D[a] in a healthy condition. At the latter point, the depth of the main should be such as to reach the bed of the clay, and prevent the water running back towards the point R, in case the inclination has a tendency to produce that effect.

134. A patch of gravel or similar material is occasionally met with in the midst of a district, the surface of which, in other parts, consists of clay, as shown in fig. 45. In

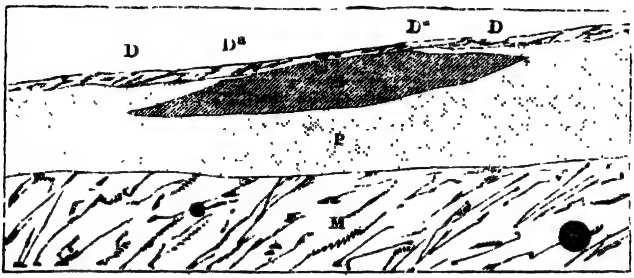
Fig. 45.



this case two sets of drains will be required, viz. at the points D D and D^a D^a; and the same remarks as to the relative depths of these mains will apply as already made in referring to fig. 43.

135. Fig. 46 shows a similar patch of clay running into

Fig. 46.



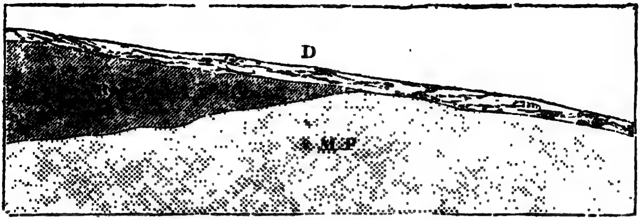
and under the gravel, requiring also two sets of main drains, which will be more effective in proportion to their depth, and the most so if they reach the bed of the clay, and thus prevent its injurious retention of the drainage water from the gravel or sand overlying its edges.

136. When the general surface of the district has a considerable inclination, as shown in figs. 47 and 48, the me-

Fig. 47.

thods of drainage to be adopted will be varied according to the relative positions of the materials. Thus, if the porous material be above, as in fig. 47, the main drain should be

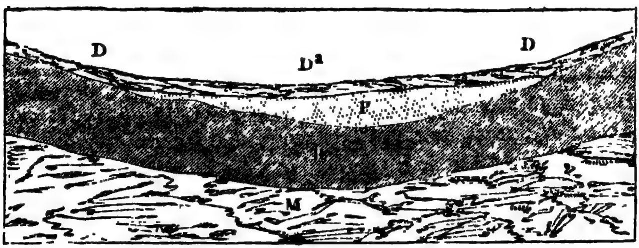
Fig. 48.



at the point D; but, if the clay lie upon a stratum of less density, as in fig. 48, the main should be laid at a lower situation, where it will naturally receive all the water which accumulates at D, besides that contained in so much of the lower bed as is above it.

137. If a bed of gravel lie in the hollow of a stratum of clay, as represented in fig. 49, the surface of the district

Fig. 49.

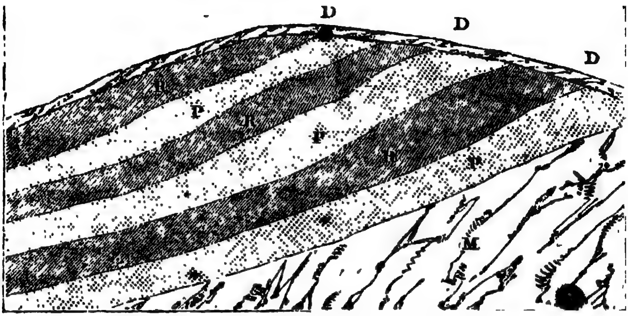


will remain tolerably dry except at the lowest point D[a], where the accumulation of water from the higher parts, resisted in its disposition to descend by the substratum of dense texture, will make a principal main drain of ample dimensions necessary. Auxiliary mains are also required at D D, to drain the clay surface above these points, and save the porous bed from the saturation which will naturally occur unless thus prevented.

138. In hilly districts, clays and gravel are often found in alternate layers, which outcrop on one side of the hill,

as sketched in fig. 50, and render a series of main drains necessary at the points marked D. By these drains, the

Fig. 50.



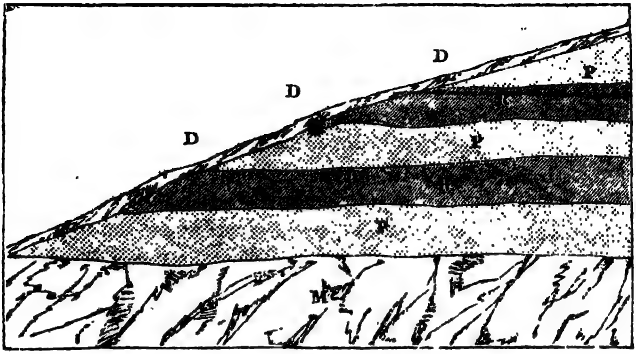
water which gathers in the retentive strata will be discharged at the lowest points on the surface, and prevent any mischievous excess on the soil. The intermediate portions of the porous materials which are exposed will readily get rid of their contents by percolation, and drains of comparatively small dimensions will be adequate to the efficient drainage of a section thus composed.

139. Sometimes the side of a hill displays a series of alternate and horizontal layers, as represented in fig. 51, in which case a small main drain should be laid at the exposed bed of each stratum, at the points marked D D, which will receive the contents of each porous layer, and prevent any injurious excess accumulating within the intermediate clays.

140. Having thus briefly noticed the several varieties of section which are likely to occur in the drainage of districts and lands, we have now to consider the form, size, and construction of drains which it will be advisable to adopt according to the circumstances of each case.

141. The rudest form of drain is that of an open cut or channel in the surface of the ground, for conveying the

Fig. 51.



water which falls in the form of rain, or percolates through the materials intersected, away into some lower position, brook, or other receiver. These open drains are distinguished from the more complete form of underground or covered drains formed by open channels, which are afterwards refilled, except at the lower part, along which a channel is preserved by one of several methods of construction. Both of these methods appear to be of great antiquity, having been certainly practised by the Romans, as recorded by Palladius, Pliny, &c.

142. The arrangement and distances apart of open drains have been usually determined by those of the ridges and furrows. Previous to the introduction of "under-draining," wet and strong lands were prepared for arable culture by being ploughed up into the undulating shape known as "ridge and furrow," the bottom of the furrow forming a rude drain for the water from the adjoining ridges. The wetness of the furrows or "thoroughs," as sometimes called, and of the slips of land adjoining, however, occasioned the perishing of the crops, and led to the adoption of shallow drains below the furrows, and commonly kept open with straw or brushwood. This was termed "furrow" or "thorough" draining. In this manner

the ordinary width of the lands or ridges in each district indicates generally the distance at which the drains were placed, and the distances now most commonly observed in different districts, and on different soils, have reference to a width of ridge that was, or is, in use in those districts ; and it is "a fact worthy of remark, that throughout the country the statements of the number of feet from drain to drain is in almost every instance divisible (when reduced to inches) by *eighteen*, that being the space of ground in inches moved by a single turn of ordinary ploughing."* The long-established usages of each district may be regarded as indicating the requirements of that district, and the distance from furrow to furrow furnishes a kind of rude index of the comparative tenacity or porosity of the soil, or its capacity for retaining or transmitting water. The tabular statement, p. 124, (as prepared by Mr. Spooner,) illustrates the correspondence of the distances between ridges and drains with the character of the soil.

143. Open drains are applicable only as conductors of surface water, and for strong tenacious soils. To make them effective in draining from the body of the soil, the depth necessary renders open drains inadvisable; while, in loose soils, the inclination of the sides, which must be allowed in order to prevent their rapid destruction, occupies a most extravagant surface of the land. They are evidently inapplicable to land submitted to the plough, by which they are almost certain to be injured or destroyed, and thus have commonly been restricted to pasture land, whence they have been named *sheep-drains*. Even as thus limited, the use of open drains is of very doubtful advisability, inasmuch as they are always much exposed to injury, and to have their banks trodden down and destroyed. Admitting permanent utility as an object in drain-making, it is certain that covered drains should, in nearly all cases, both for arable and pasture districts, be preferred to open ones.

* Evidence of L. H. Spooner, Esq., of Balmacara House, Loch Alsh.

Width of Land or Ridge.	No. of turns of the Plough (18 in. wide) to the land.	Some of the Districts in which the respective widths of Ridge are in common use.	General character of the Soil.	Distance from Drain to Drain, in common use.
ft. in. 7 6	5	Common in the county of Essex.	Tenacious and uniform clay.	7 ft. 6 in., 15 ft., 21 ft., or every furrow, every other furrow, every third furrow, &c.
16 6	11	Parts of Surrey, Sussex, Kent, Middlesex, &c.	Same as above, fine and silthing clays, with beds of fine sand interspersed.	Drains 1 rod apart.
18 0	12	Parts of Yorkshire, Northumberland, South of Scotland, &c.	Clays, containing coarse sand and grit, interspersed with shale and slate fragments.	Drains 18 ft. or 1 rod (Scotch measure) apart.
21 0	14	Common in the above and the Midland Counties, &c.	Calcareous soils and clays, lighter than the above, with frequent intermixtures of sand and gravel.	Drains 21 ft. apart.
24 0	16	Very common in the Midland Counties and the Highlands.	Clays, similar to the above, with rotten sandstone rock and more frequent intermixtures of gravel, &c.	Drains 24 ft. apart.
30 0	20	Very generally adopted in the lighter clays throughout the country.	The lighter description of clays and clay gravels.	Drains 30 ft. apart.
33 0	22	Parts of Berkshire, Herts, Suffolk, Cambridgeshire, &c.	Chalk districts, stone, brush, gravelly, and sandy soils, and the lighter description of lands, usually springy soils.	Drains 33 ft. or 2 rods apart.
36 0	24	Same as above, and very general.	......	Drains 36 ft. or 2 rods (Scotch measure) apart.

The application of furrow drainage to the two last is comparatively of recent date.

144. For suburban and road drainage, the reasons for preferring covered to open drains have still greater force than those applicable to land drainage. These reasons are not only economical, but also sanitary. Open drains, presenting a commonly stagnant water surface to the atmosphere, produce an unwholesome evaporation. Decayed vegetable matter accumulates in these drains or ditches, and emits the most offensive effluvia. Near the metropolis there are many large open watercourses, which serve to carry away flood waters, when such occur, but at other times the small quantity of water in these channels moves sluggishly over their rugged beds, or lodges in stagnant pools. These ditches sometimes serve as outfalls for the drainage of suburban houses, and the effluvium then becomes at times highly noxious and even fatal. The courses of these ditches were marked by excessive ravages of cholera among the adjoining population.

145. In carrying out land-drainage, the open roadside ditches are usually found to present most serious obstructions to the work; but if road-drainage were placed, as it should be, in proper subordination to the general system, covered tubular drains for the roads would of themselves effect considerable land-drainage, and in some districts closely intersected with by-ways and public footpaths, they would sometimes supersede the necessity for any other drainage. On a very stiff clay soil a road drain might, perhaps, not act more than from 12 to 15 ft. on either side of it, but in freer soils a single drain would frequently serve a width of from 1 to 2 chains. These road drains, properly constructed, would generally answer as excellent outfalls for the drainage of the land.

146. The extent of evaporating surface of stagnant moisture with decomposing vegetable and animal matter presented by the open ditches on both sides of a mile of road, equals from three quarters to one acre; that is, by the substitution of covered drains, three quarters to one acre would be gained as dry road, or cultivable land for each

mile of road, besides removing a frequent cause of accidents with horses and vehicles.

147. Covered drains, being simply intersticial courses formed beneath the surface, may be constructed in a great variety of ways, which may be partly determined by the proximity of the suitable materials. One of the simplest forms, and most generally applicable, consists of a layer of stones in the bed of the drain, which is afterwards filled up with the soil taken out of it in order to deposit the stones, as shown in fig. 52. In these drains there is a liability to

Fig. 52.

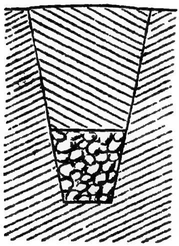


Fig. 53.

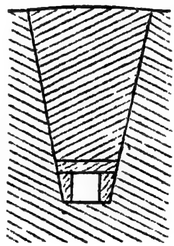
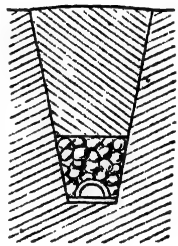


Fig. 54.



become less active, by particles of soil being forced down or brought into the water, and clogging the spaces left for its passage. If stratified stone is cheaply obtainable, the better arrangement represented in fig. 53 should be adopted, consisting of side stones, and one cover over them, leaving an open space or duct through which the drainage water passes of course more fluently than through the spaces between the stones, as shown in fig. 52.

148. A compound drain, composed of a layer of loose stones, and an artificial duct formed with a flat tile on the bed of the drain, and covered with a semi-cylindrical tile, as shown in fig. 54, combines the advantages of the two preceding drains. This form is commonly denominated the *sole and tile drain*, and may, in most parts of the country, be constructed at less cost than the stone duct shown in

fig. 53. It has also the advantage of greater permanency, being less liable to displacement of the parts. In the drain shown in fig. 53, the same arrangement of stones over the duct may of course be introduced; but unless the work is very carefully done, and the covering with the flat stones rendered perfect, the loose stones are liable to fall into the duct, and thus destroy its utility.

149. In clays and tenacious soils, drains such as that shown in fig. 55 are sometimes formed by cutting the lower

Fig. 55.

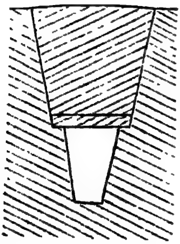


Fig. 56.

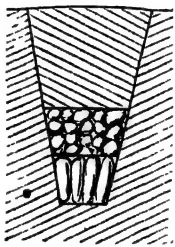
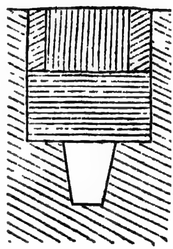


Fig. 57.



part narrower on each side, and thus leaving shoulders, on which a flat stone being supported, an open space is left below, forming a natural duct or open passage for the water. The permanence of this, *the shoulder drain*, is somewhat insecure, as it depends solely upon the shoulders being preserved, and the qualification of the material to resist all damage to the open parts of the drain. Another form of rough stone drain is represented in fig. 56, for which the larger stones are assorted, and placed in the bed with a layer of small stones upon them. It must be remarked of this, however, as of every rough stone drain, that its permanent action, depending upon the small spaces left between the stones, is very liable, in the course of time, to become much impaired or destroyed by the particles of soil and solid matters brought along with the drainage water; and on this account, especially, these drains are far inferior to those constructed with permanent open ducts.

150. Fig. 57 shows a drain suitable for bog and peaty soils, with which the drain is filled up, leaving an open space below for the passage of the water. The principal objection to this form of construction in peat is, that the effect of dry seasons is to contract the materials, which then get shifted by the superincumbent weight, and sometimes choke the watercourse below. For the purpose of protecting the water-way of drains, turf is occasionally placed over the stones, as shown in fig. 58, where the water-

Fig. 58.

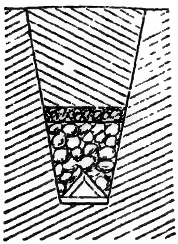


Fig.

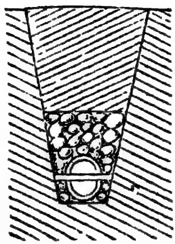
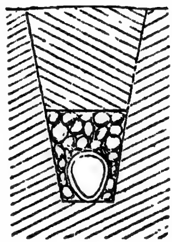


Fig. 60.



course is formed with three flat stones, or otherwise tiles, arranged as the sides of a triangle, and leaving an open duct between them. This duct is covered with a layer of loose stones, by which the stones forming the duct are kept in their places, and upon these stones a layer of turf is placed before filling the drain up with the soil.

151. Fig. 59 represents a compound drain, having two clear watercourses, and a layer of loose stones for interstitial drainage. The two courses are formed with two semi-cylindrical tiles, and a flat tile or sole between them. In all drains formed with soles and tiles, these are laid so that the joints in one break with those in the other; by which the joints are rendered less liable to be dislocated or disturbed than they would be if the joints in the soles and the tiles were laid coincident with each other.

152. The most complete and undoubtedly permanent form of drain is that which consists of an open channel

formed entirely of single pieces of tile-work or piping. These are now generally acknowledged to form the most superior drains; and, in nearly all places in this country, their cost will not much exceed that of the imperfect drains formed with loose stones. A drain of this construction is shown in fig. 60, where the earthen pipe is represented of an egg-shaped section, and a layer of loose stones placed above it. If drains be thus formed, the joints accurately laid, and the whole work carefully done, the drainage will remain in a perfect and unimpaired condition for a very long period.

153. Drains are liable to injury by vermin, as well as vegetation, the roots of trees, &c., acting in a very injurious manner when their progress is interrupted by underground constructions for drainage. Drains should, therefore, be laid apart from trees, or these cleared away before constructing the drains. The liability to injury by vermin is one feature in which pipe drains are superior to all others constructed of several parts, or depending partly upon the permanent position of the soil in which the drain is formed.

154. The form of construction being determined, the *size* of the drains is the next object of consideration. Formerly drains were commonly made of small depth. But deeper ones having been subsequently constructed, and considerable efficiency in the effect obtained, a great desire has arisen for *deep drains.* In arable districts one imperative condition as to the depth of drains is, that the lower and constructed part of the drain shall be below the action of the plough and other agricultural implements. The structure, depth, and position of the strata are also circumstances that will deserve regard in fixing the depth, as already explained at length in describing the several varieties of sections; and, besides these, another consideration, which must be kept in mind, is, the rate of fall which can be obtained, according to the levels of the surface of the district, to assist the discharge of the contents of the drain,

As a general principle, if it were impossible to allow all these circumstances their due weight in arriving at a decision as to the depth of the drains, *deep* drains are doubtless more safe and likely to be efficient than *shallow* drains; but while all the facts exist, and may be ascertained, by which the depth should be regulated, it is mere blind prejudice which advocates *deep drains* in all cases and under all circumstances.

155. On the *depth* of drains, the following observations by the late Mr. Smith, of Deanston, are deserving of careful consideration:—"Estimating the thorough drainage of land by the cubic contents of the soil, reckoning from the level of the bottom of the drainage to the surface of the ground, can give no exposition of the agricultural effect, because it has not yet been fully determined by experiment or in practice how far it is beneficial to the growth of plants to remove the *free* water from the lower regions of the subsoil. One set of experiments over a course of three years has been furnished by Mr. Hope, of Foreton Burn, in East Lothian, from which it appears that the results were in favour of moderate depths of drains; and the practice in the Fens of Lincolnshire shows that the most beneficial distance from the surface for the free water is about 2 ft. In dry seasons, when the water in the level ditches falls below 2 ft. from the surface, the crops are found to suffer, and it is customary to dam up the water to that level.* Water will rise some inches in soil by capillary or molecular attraction; but in such cases the water never fills the fissures or interstices of the soil to such an extent as to exclude the atmospheric air, but merely attaches itself to the surface of the particles of soil, and of the smaller cells and channels in the soil, where it remains available to the roots of plants, and without any of the bad effects resulting from stagnant *free* water. Until the great point

* The expediency of this practice is questioned by J. A. Clarke, Esq., in an elaborate report upon the farming of Lincolnshire. See Journal of the Royal Agricultural Society, vol. xii. p. 326.

can be fully and practically determined as to the proper distance for retaining a supply of water, the depth to which land should be drained cannot be pronounced. The rule, when ascertained, will probably be found to vary with the nature and condition of the soil. In removing water falling on the surface, it has been found in practice, and which agrees with a great theory, that having the artificial channels at near distances, and not over deep, is most effective in the immediate and complete removal of the free surface water. Distances of from 18 to 24 ft., with depths of from 2 ft. to 3 ft., have been found, over extensive tracts, and in soils of various texture, to effect complete thorough-drainage for agricultural purposes."

156. As an advocate of deep draining, Mr. Elkington must be named as connected with some very successful experiments in treating land, which astonished the good farmers of the last century, who had been accustomed to pay very little attention to the improvement of their lands in this manner, and had been satisfied to trust the aqueous condition of their broad fields to the hedge-ditch and ridge-furrow. Mr. Elkington, having a farm called Princethorp, in the parish of Stretton-upon-Dunsmore, county of Warwick, of which the soil was very poor, and so wet that the sheep rotted by hundreds, turned his attention to the best means of draining it. For this reason he began operations in a field of wet clay soil, made nearly a swamp, and in some parts a shaking bog by the springs of water which issued from an adjoining bank of gravel and sand. Mr. Johnstone, who published an account of Mr. Elkington's "system," thus describes his proceedings:—"In order to drain this field, he cut a trench about four or five feet deep a little below the upper side of the bog, or where the wetness began to make its appearance; and after proceeding with it so far in this direction, and at this depth, he found it did not reach *the main body of subjacent water*, from whence the evil proceeded. On discovering this, Mr. Elkington was at a loss how to proceed. At this time,

while he was considering what was next to be done, one of his servants accidentally came to the field where the drain was making, with an iron crow or bar, which the farmers in that country use in making holes for fixing their sheep-hurdles. Mr. Elkington, having a suspicion that his drain was not deep enough, and a desire to know what kind of strata lay under the bottom of it, took the iron bar from the servant, and after having forced it down about four feet below the bottom of the trench, in pulling it out, to his astonishment, a great quantity of water burst up through the hole he had thus made, and ran down the drain. This at once led him to the knowledge of wetness being often produced by water confined further below the surface of the ground than it was possible for the usual depth of drains to reach, and induced him to think of employing an auger, as a proper instrument in such cases."

157. These proceedings took place in the year 1761, and it is very evident, from Mr. Johnstone's account of Mr. Elkington's *discoveries*, and the principles upon which he conducted his draining operations, as distinguished from the methods then in common use, that these methods were adopted without any reference whatever to the leading circumstances which properly regulate the steps to be taken. Thus the three leading points observed by Mr. Elkington, were, "1st, finding out the *main spring*, or cause of the mischief;" "2nd, taking the level of that spring, and ascercertaining *its subterraneous bearings;*" a measure never practised by any, till Mr. Elkington discovered the advantage to be derived from it; "and 3rd, making use of the auger to reach or *tap* the spring, when the depth of the drain is not sufficient for that purpose."

158. The process of tapping is evidently available only when the spring is fed from a higher level, so that the pressure shall suffice to force the water upward through the auger-hole. Another method is sometimes adopted as a substitute for the auger-hole or vertical bore, namely, digging a well of depth proportioned to the pressure, and

filling this well with loose stones, through which the water will rise, and thence pass away along the drain, with the bed of which the well communicates. Similar auger-holes, or wells, may be adopted to effect the precisely opposite object, viz. to make a downward passage of the drainage water from the drains which intersect an upper and clay stratum only, into a more porous bed beneath, in the body of which the water will become dispersed.

159. The cheapest method of forming open drains in grass land is by turning a furrow-slice over with the plough, and afterwards trimming it with the spade, the lines for the drains being previously marked with poles. The *cost* of these drains will not exceed one halfpenny per rood of six yards, which is the measure we shall adopt in all cases where the quantity is stated in *roods*. This mode of operating is inadvisable if the grass be rough and long, so that the plough is apt to become choked, or if swampy places occur. In such cases, it is far better to do all the work with the spade, by which the cost will be increased to 2*d*. per rood, if the drain be formed about 9 in. wide in the bed, 18 or 20 in. at top, and about 18 in. deep, which is a good size for the minor or sub-drains. Covered drains may be formed in grass-land 6 in. wide in the bed, 18 at top, and about 16 in. deep, at 4*d*. per rood, by cutting out the upper turf, the whole width across the cut, with the spade, casting out the lower portions subsequently, and then carefully replacing the turf, thus leaving an open space below, equal to the quantity cast out. The permanence of this drain is, however, very insecure; and, if cattle are admitted on the surface, they will certainly tread the turf to the bed of the drain, and thus destroy it. The first cost will, moreover, nearly equal that of a pipe drain, which needs a much narrower cut, and will remain permanently efficient.

160. In land to be planted with forest trees, open drains are always to be recommended, as covered ones are certain of destruction by the natural tendency of the roots of the trees to choke them in their search for moisture during dry

seasons. The main drains should be laid along the hollows in the surface, and made at least 3 ft. deep, with a flat bed 1 ft. wide, and the banks inclined at the rate of $1\frac{1}{2}$ base to 1 perpendicular, except in firm clay soils, in which the banks may be formed much steeper. The minor drains should be for clays not less than 20 in. deep, and light soils 14 in., with a bed in both cases 9 in. in width, and the inclination of the banks regulated as for the mains. The cost of the former will be about $1\frac{1}{2}$*d.* per rood, and the latter 3*d.* per rood. The cost of the mains will be in nearly the same proportion, according to the quantity of soil removed. The best distance at which to lay the minor drains from each other will vary in extreme cases from 5 to 40 yards, according to the levels of the site and character of the soil, the retentive clays requiring the drains closer than the lighter soils.

161. A general and *most important principle* as to the *capacity* of drains of all kinds whatsoever is, that it should *exceed* rather than *be deficient of* the dimensions ordinarily required to discharge the quantity of water for which provision is to be made. The principal use of a drain being to attract water towards it through the soil, besides passing the water thus collected away, its dimensions cannot be adequately estimated by simply considering the quantity to be conveyed within any given time. These dimensions should, therefore, be such as to present large surfaces of the soil intersected, and, other circumstances being the same, the efficiency of the drain will be in proportion to the extent of the surfaces; that is, to the depth of the drain. But, on the other hand, if the greater depth of the drain causes it to intersect porous strata overcharged with water from higher land, it will become injurious rather than beneficial, and this evil will be much aggravated if the greater depth be admitted as a reason for the proportionate infrequency of the drains. There can be no doubt that, in tenacious soils, shallow drains laid closely are, within certain limits, more useful than deep drains laid wide apart;

but, if contiguity can be observed, the deeper they are made the better, in ordinary cases.

162. Some reasons to guide the depth of drains may be derived from a consideration of the action of the soil upon the water which reaches it, as produced by its mechanical structure. Thus, in light and porous soils, the force of gravity is active in carrying the water to the bottom of the stratum; whereas, in the dense clays and soils, a certain capillary action is exercised upon the water introduced to them, which tends to raise it from the bed, and sustain it in general diffusion throughout the mass. Therefore, while porous soils evince little or no water on the surface, the lower part of the layer will be kept in a state of excessive wetness if it lies upon a clay bed; and, if its thickness be such that the roots of the vegetation reach the wet, the depth of the drains should at least equal that of the porous soil, so that the entire body may be relieved of the water. On soils of this nature, shallow drains are utterly useless, unless they happen to reach an impervious subsoil, and conduct the water into mains of greater depth.

163. In arable land, the minimum depth for covered drains may be estimated upon the depth to which the plough penetrates, and making such an allowance below this depth as will secure the materials of the drain from disturbance under any circumstances. Mr. Stephens calculates the depth of a furrow-slice with a two-horse plough at 7 in.; but in cross ploughing, 9 in. If four horses be used, the depth of the furrow will be 12 in.; and if the four-horse plough follow the common one, the depth will be increased to 16 in. Subsoil ploughing will penetrate 16 in. below the common furrow of 7 in. Allowing 3 in. between the lowest disturbed part of the soil and the surface of the materials in the drain, and restricting the effectiveness of the drain to that portion of it which is below the ploughed surface of 7 in. in depth, the minimum depth of drains should be such as to allow 19 in. below the furrow-slice, or 26 in. below the surface and above the constructed portion

of the drain, and so much more than this if subsoil ploughing be practised. Allowing 6 in. for the depth of the drain occupied by the pipes or tiles, Mr. Stephens estimates 33 in. as the minimum depth of drains in porous subsoils, and 50 in. in clay subsoils, with an additional 6 in. in each case if stones are employed as filling materials in the drain.

164. The size for the water-passage or duct of a drain should be determined by reference to a variety of circumstances, the combined influence of which may generally be estimated in practice, although not reducible to any very exact rules. Thus, the quantity of rain which falls upon the surface has to be considered, not as an annual or season quantity, but as a maximum per diem. Then, the nature of the soil and the state of the atmosphere, as affecting the ratio of evaporation, require attention. Beyond these considerations, the general level of the district in relation to the surrounding country, by which the tract to be drained may be made the recipient of foreign waters, on the one hand, or kept in a dry condition by the action of gravity, on the other, must be noticed. Again, the structure of the soil affects the quantity of the water which passes through it, and also the rapidity of its passage; and the amount of water to be met with will be modified by the part of the stratum at which the drain is situated. Thus, in porous materials, smaller ducts will suffice in the top of the layer than are required below; and the dimensions must be increased in proportion to the depth of soil above. As an auxiliary fact in enabling us to determine the capacity of the ducts of drains, the frequency of them upon the plan of the district will be greatly influential.

165. The best evidence on these points, viz. the dimensions and distance of drains, is to be gathered from the records of extended practice. In the weald-clay of Kent, which is commonly of a very tenacious character on the surface, but milder below, the body of the water naturally passes downwards until arrested by a more retentive stra-

tum, and, therefore, the deeper the drains the more efficiently they will act. In other parts of the weald, the soil is compounded of the supersoil or cultivated earth and of a strong clay, upon which it lies. This soil admits of percolation; but the tenacious clay beneath it does not, and, if this clay be at a considerable depth from the surface, there will be little utility in carrying the drains into it. In these strong clays, not subject to springs, drains $2\frac{1}{2}$ ft. deep have been found *more* efficacious than those made 4 ft. deep. In the heavy lands of Norfolk, the drains which answer best are $2\frac{1}{2}$ ft. deep, and laid at the distance of 22 ft. apart. When they are made deeper, in clay in which flint and chalk boulders are found dispersed about, the labour of taking out the lower bed of 16 or 18 in. is very expensive, costing in that county from 6 to 8 pence per rod of $5\frac{1}{2}$ yards. In the clay-lands of Hampshire, the drains made from 30 to 36 in. in depth, and 18 to 24 ft. apart, have been found most successful. We can readily understand that, as vegetation requires a certain amount of moisture, it is possible to *drain* land so effectually that sufficient moisture is not left to fulfil the purposes of cultivation, and the clay soils, which are so reluctant both to receive and to discharge water, will yet suffer a slow and sure deprivation through the agency of deep drains, which will be injurious to the health of vegetation; while drains of less depth would have left the lower part of the stratum in a damp condition, and capable, by the capillary action of the soil itself, of supplying the entire mass with a genial moisture. In Lincolnshire it is a known fact, that if the water in the ditches is reduced to a level below 3 ft. in depth from the surface, the grass-land is, in dry summers, most decidedly injured. In the neighbourhood of Folkingham, a tract of clay land was, several years ago, drained with tiles laid 3 ft. 6 in. deep, and the surface, which was in broad bands with high ridges, was levelled. After a short period, however, the texture of the clay became so solid that the surface-water could not get down to the drains, and it became necessary to alter the

method. On the same lands, drains now made 18 or 24 in deep are found entirely successful. In the neighbourhood of Newcastle-on-Tyne, some clay lands have been drained by drains laid 2½ ft. deep and 20 ft. apart, with highly satisfactory results. In various parts of Scotland, the subsoils of retentive clay have been more completely drained by drains 2½ ft. deep and 18 ft. apart, than by 4-ft. drains laid 36 ft. apart. In the counties of Worcester, Hereford, &c., the best drains in the clays are those laid from 2 to 3 ft. in depth; those made 4 and 5 ft. deep being found far less effective. Mr. Tebbet of Mansfield, near Nottingham, states that the *best* way he has adopted on strong clay lands is putting the drains 14 ft. apart and 2 ft. deep; while he finds other clays that will draw at 18 to 24 ft. apart, and 2 to 3 ft. in depth for the drains.

166. A kind of average scale for the dimensions and distances of drains may be drawn from the experience we have hitherto had in the draining of land. Classifying the varieties of soils into three divisions, as *Compact* or *Heavy*, *Medium*, and *Porous* or *Light*, each of which may be subdivided into several degrees of retentiveness or porosity, the distance of the drains apart may be graduated from 15 to 66 ft., and their depth range from 2 ft. 6 in. to 4 ft. 6 in., as in the Table, p. 139, which has been adopted by the General Board of Health in their "Minutes of Information."

167. The *cost* of draining is necessarily a theme of deep consideration in the execution of any plan which appears likely to be most successful. The following records state the size and distance of the drains, the nature of the soil, and the total expense *per acre*.

The first eight of these cases are quoted from Mr. Smith's (of Deanston) Pamphlet. They are instances of hard subsoils, with tiles and soles.

Nos. 9 to 16 are cited by Mr. Josiah Parkes, in the 6th vol. of the "Journal of the Royal Agricultural Society," the drain-pipes being supposed to be made upon the estate, and costing 6*s*. per thousand.

A TABLE OF THE COST OF LAND-DRAINAGE PER ACRE.

The differences in the quality of soils, that lead to differences in the depth and distance of the Drains, are also such as to affect the cost of digging the Drains. An increase of depth necessarily causes an increase of cost, from the mere circumstance of more earth having to be moved. But the same reason that causes Drains to be made closer, namely, the stiffness of the soil, renders them more difficult to dig, and hence increases the price of digging. This will explain how it happens, in the following Table, that the cost per rod is greater, not only as the depth increases, but as the distance of the Drains is less. Of two soils drained at the same depth, the expense of draining a rod will be least in that for which the Drains are furthest apart, which is where the soil is of the freest or least tenacious description.

Description of Soils.		Distance of Drains apart.	Depth of Drains.	Number of Yards of Drains per Acre.	Cost of cutting and filling per Chain.	Cost of cutting and filling per Acre.	Number of Drain Pipes of 12 in. long required per Acre.	Cost of Drain Tiles per Acre, at 30s. per 1000.	Total Cost per Acre.
		ft.	ft. in.		£ s. d.	£ s. d.		£ s. d.	£ s. d.
Compact or heavy Soils.	Compact tenacious gravelly Clay.	15	2 6	968	0 1 8	3 13 4	2905	4 7 2	8 0 6
	Stiff adhesive Clay.	16½	2 6	880	0 1 7	3 3 4	2640	3 19 2	7 2 6
	Friable Clay	18	2 9	807	0 1 6	2 15 1½	2420	3 12 7	6 7 8
	Free soft Clay	21	2 9	692	0 1 4	2 2 0	2076	3 2 3	5 4 3
Medium Soils.	Clayey Loam	22	3 0	660	0 1 8	2 10 0	1980	2 19 5	5 9 5
	Marly Loam	24	3 0	605	0 1 6	2 1 3	1814	2 14 5½	4 15 8
	Gravelly Loam	27	3 3	538	0 2 4	2 17 2	1613	2 8 4½	5 5 6½
	Friable Loam	30	3 3	484	0 2 0	2 4 0	1452	2 3 6½	4 7 6½
Porous or light Soils.	Light gravelly Loam	33	3 6	440	0 2 10	2 16 8	1320	1 19 7	4 16 3
	Light Marly Loam	36	3 9	403	0 2 8	2 9 4	1209	1 16 3	4 5 7
	Sandy Loam	39	4 0	373	0 2 6	1 19 8	1117	1 13 6	3 3 2
	Soft light Loam	42	4 0	346	0 2 4	1 16 9	1037	1 11 1½	3 7 10½
	Sandy Soil	45	4 0	325	0 2 4	1 14 5	974	1 9 2½	3 3 7½
	Light gravelly Sand	49½	4 3	293	0 3 4	2 5 0	880	1 7 4½	3 12 10
	Deep do. do.	55	4 3	264	0 3 0	1 16 0	792	1 3 9	2 19 9
	Coarse gravelly do.	60	4 6	242	0 4 0	2 4 0	726	1 1 9	3 5 9
	Loose do.	66	4 6	220	0 3 4	1 13 4	660	0 19 9½	2 13 1½

The remaining cases are also given by Mr. Parkes, viz. in the "Gardener's Chronicle," the tiles being made upon the estate, and drawn by the tenants.

No.	Soils.	Depth of Drains.	Distance between the Drains.	Cost of Labour per Acre.			Cost of Pipes or Tiles per Acre.			Total Cost per Acre.		
		Ft.	Ft.	£	s.	d.	£	s.	d.	£	s.	d.
1.	Clay	..	15	2	11	4	3	0	11¼	5	12	3¼
2.	Sandy clay	..	18	2	2	10½	2	10	9¾	4	13	8¼
3.	Ditto	..	21	1	16	9	2	3	6¼	4	0	3¼
4.	Free stony subsoil	..	24	1	12	1	1	18	1¼	3	10	2¼
5.	Ditto	..	27	1	8	7	1	13	10¼	3	2	5¾
6.	Porous	..	30	1	5	8	1	10	6	2	16	2
7.	Ditto	..	33	1	3	4	1	7	8½	2	11	0½
8.	Sand or gravel	..	36	1	1	7	1	5	4	2	6	11
9.	Uniform clay	3	33	1	0	0	0	7	11	1	7	11
10.	Ditto	3	33	1	0	0	0	7	11	1	7	11
11.	Ditto	3 to 4	33	1	6	8	0	7	11	1	14	7
12.	Ditto	4½ to 4	40	1	2	0	0	6	6	1	8	6
13.	Clay, with some stones	4	50	1	6	6	0	5	3	1	11	9
14.	Clay. Hard gravelly subsoil	3 to 3½	49½	1	15	6	0	5	4	2	0	10
15.	Ditto	4	49½	1	15	6	0	5	4	2	0	10
16.	Various. Clay, gravel, sand	4	66	1	6	8	0	4	0	1	10	8
17.	Clay. Gravelly subsoil	3½ to 4	33	2	10	0	0	7	11	2	17	11
18.	Heavy clay	4	36		..			..		4	11	7
19.	Various clay	4	36		..			..		3	15	5
20.	Strong clay	4	30 to 33		..			..		4	4	2
21.	Strong land	4	39		..			..		4	15	7
22.	Weak blue clay	4	30		..			..		4	13	11
23.	Whitish stubborn clay	4	36		..			..		4	16	1
24.	Strong clay and gravel	4	33 to 36		..			..		5	3	4
25.	Whitish clay	4	36		..			..		4	4	8

168. The several items of cost of draining a rectangular field of 20 acres, with drains 3 ft. deep, and 22 ft. apart, may be averaged thus:—

	£	s.	d.
Main drain, 60 rods, at 8½*d.* per rod for cutting and filling	2	2	6
Drain-pipes, 990, at 40*s.* per thousand	1	19	7½
Minor drains, 2261½ rods, at 4½*d.* per rod	42	8	0
Drain-pipes, 37,320, at 30*s.* per thousand	55	19	7
	£102	9	8½

Equals 5*l.* 2*s.* 6*d.* per acre.

The main drains are supposed to be 3 ft. 6 in. deep, 20 in. wide at top, and 4 in. in the bed, with pipes 4 in. in dia-

meter. The minor drains are supposed to be 3 ft. deep, 15 in. wide at top, and 3 in. in the bed, with pipes 3 in. in diameter.

169. The several items of cost of draining a similar rectangular field of similar soil, and prices for cutting and filling in proportion to the sectional area of the drains; the field being, as before, 20 acres in extent, with drains $4\frac{1}{2}$ ft. deep, and 45 ft. apart, may be estimated thus:—

	£	*s.*	*d.*
Main drain, 60 rods, at 1*s.* 2*d.* per rod for cutting and filling	3	10	0
Drain pipes, 990, at 40*s.* per thousand	1	19	$7\frac{1}{2}$
Minor drains, 1109 rods, at 10*d.* per rod for cutting and filling	46	4	2
Drain pipes, 18,300, at 30*s.* per thousand	27	9	0
	£79	2	$9\frac{1}{2}$

Equals 3*l.* 19*s.* $1\frac{1}{2}$*d.* per acre.

The main drains are supposed to be 5 ft. deep, 24 in. wide at top, and 4 in. in the bed, with pipes 4 in. in diameter. The minor drains are supposed to be 4 ft. 6 in. deep, 21 in. wide at top, and 3 in. in the bed, with pipes 3 in. in diameter.

170. Mr. Smith gives estimates for drains constructed with reference to the nature of the soil, which may be arranged as in the Table given on p. 142.

Mr. Smith also mentions a district of 10,000 acres of stiff compact clay soil in Scotland, which has been satisfactorily drained with drains 2 ft. deep, and laid 20 ft. apart.

171. The principal circumstances which determine the cost of drainage works are—the labour of cutting and filling the drains; the material of which the drain itself is formed; and the outlets for the discharge of water. Of these, the last increases in proportion as the ground is steep and irregular, or unusually flat, and can only be included, in a general estimate, where the surface gently undulates; the material also varies greatly in cost, arising, in

Soils.	Depth of Drain.	Distance of Drains.	Cost per Acre. Cutting and Filling.	Materials.—Tubes, at 20s. per thousand.	Chargeable for Mains, Outfalls, Superintendence, &c.	Total.
	Ft. In.	Ft.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Alluvial clay	3 0	21	2 1 10	2 2 0	0 18 0	5 1 10
Upland clay or till, full of stones.	2 9	21	3 2 9	2 2 0	1 2 0	6 6 9
Compact gravelly drift, with boulder stones.	2 9	24	3 4 0	1 16 3½	1 1 0	6 1 3½
Open sand and gravel, with moorish bottom.	4 0	40	3 6 0	1 1 9¼	1 2 0	5 9 9¼
Peat moss, forming its o chan-nel.	3 6	18	1 4 5	..	0 6 0	1 10 5

the case of tiles, in the supply being near at hand, and equal to the demand, or otherwise; and, in the case of stones, in the distance of carriage.* The following table supposes

Description of Drains.	Depth of each Drain.	Width at top.	Width at bottom.	Average Width.	Running yards of Drain to the cubic yard.	Sandy Soils, light Loams, and light Clays; easy digging. At 4d. per cubic yard. Per yard.	Per rod.	Stiffer Clay and Gravel, requiring some pickwork. At 6d. per cubic yard. Per yard.	Per rod.	Hard Clay and close Soils, requiring pickwork. At 8d. per cubic yard. Per yard.	Per rod.
	ft. in.	in.	in.	in.		s. d.	s. d.	s. d.	s. d.	s. d.	s. d.
Stone Drains, as in Fig. 56.	4 0	18	8	13	2+†	0 2	0 11	0 3	1 4½	0 4	1 10
	3 6	16	8	12	2¼−	0 1⅗	0 9	0 2⅔	1 1½	0 3⅓	1 5½
	3 0	12	6	10	3½+	0 1 1/7	0 6¼	0 1 5/7	0 8½	0 2⅓	1 0½
Pipe Tile Drains.	4 0	18	3	10½	2½+	0 1⅗	0 9	0 2⅔	1 1½	0 3⅓	1 5½
	3 6	16	3	9½	3½	0 1 1/11	0 7	0 1 11/14	0 10½	0 2 6/7	1 2
	3 0	12	3	7½	5 1/15	0 0¾	0 4½	0 1½	0 6½	0 1½	0 8½

* See Mr. Spooner's evidence—"Minutes of Information," collected by the General Board of Health, 1852.

† The signs + and − imply a small fraction greater or less than the number stated.

In the price per rod, the fractional parts are reduced to the farthings nearest to them.

two sets of drains, the one opened for stones (as illustrated in fig. 56), the other for pipe-tiles, and at depths of 3 ft., 3½ ft., and 4 ft. respectively. The table shows the average width of cutting for each size and sort, and the number of lineal yards required to equal a solid yard.

172. Stones, as used for the filling of drains, are of two kinds, viz. the pebbly, or round stones, obtained from the sea-coast, or channels of inland streams, and the fragments produced by breaking up stratified or other rocks, and procured from the quarry. Of these, the former are much superior as the materials for drains, as they preserve the interstitial channels more permanently than the angular scraps from the quarry, the several projections of which are liable both to block up the spaces, and to be broken off by ramming, and thus interfere very mischievously with the passages for the water. As to the size of the stones, the standard commonly prescribed, namely, the "size of a goose's egg," is as good as any. At any rate, none should exceed 4 in. in diameter, or be less than 2 in. In all cases the stones should be assorted according to size, and used separately. Carelessness, in this respect, often leads to the complete choking of the drain, by the smaller stones filling up the spaces between the larger ones, and forming an impermeable dam across the drain.

173. Mr. Roberton, of Roxburghshire, who has paid much attention to the construction of rough stone drains, adopts these dimensions for them, viz. 33 in. deep, 7 in. wide at bottom, and 9 in. wide at the height of 15 in. from the bed of the drain, which is the space filled with stones in the manner shown in fig. 52, p. 126. Fifteen cubic feet of stones will fill this space in a rood of 6 running yards of such a drain. Mr. Stirling makes his drains of this description: 30 in. deep in the furrows, 5 in. wide in the bed, and 8 in. wide at a height of 15 in. from the bed. A rood of this drain will be filled to a depth of 15 in. by 12·3 cubic feet of stones. Inasmuch as the durability and efficiency

of these drains will be nearly in proportion to the space allotted to the stones, it is desirable, if the means will allow such an expense, to make the bed of the drain somewhat wider than here stated. Mr. Stephens prefers 9 in. width of bed, and 18 in. depth of stones, in a drain 36 in. deep.

174. The *cost* of Mr. Roberton's drains is thus stated by Mr. Stephens:—The drains being laid from 30 to 36 ft. apart, and the subsoil favourable to drainage. The averages of these distances gives 70 roods, of 6 yards each, of drains to the imperial acre.

	£	s.	d.
Opening drains 33 in. deep, and 7 in. wide at bottom, at 5½*d*. per rood of 6 yards, for 70 roods	1	12	1
Preparing stones 4 in. diameter, at 4*d*. per rood	1	3	4
Carriage of stones, at 4½*d*. per rood . . .	1	6	3¼
Unloading carts, and moving screen barrow, at ¾*d*. per rood	0	4	4½
Filling in earth, at ¼*d*. per rood	0	1	5½
Extra expense in the main drains	0	10	0
Per acre of 70 roods . . .	4	17	0½
Or per rood of 6 yards . .	0	1	4¾

In another instance, the expenses were as follows:—

	£	s.	d.
Opening drains 28 in. deep, and 7 in. wide at bottom, at 4*d*. per rood of 6 yards, for 70 roods	1	3	4
Preparing stones, at 2½*d*. per rood . .	0	14	7
Carriage of stones, at 2¾*d*. per rood . .	0	16	0½
Carried forward	2	13	11½

	£	s.	d.
Brought forward	2	13	11½
Unloading carts, and moving screen barrow, at ½d. per rood	0	2	11
Filling in earth, at ¼d. per rood	0	1	5½
Extra expense in the main drains . .	0	10	0
Per acre of 70 roods	3	8	4
Or per rood of 6 yards .	0	0	11¾

From these two instances, Mr. Stephens deduces 1*s.* 1*d.* as the average cost per rood, the average depth being 30½ in., and he has calculated a Table, which we give here, omitting the smaller fractions:—

Subsoils to which the Distances are applicable.	Distances between the Drains, in Feet.	Roods of Drains per Acre.	Cost per Acre.
HARD TILL	10	242	£13 2 2
	11	220	11 18 4
	12	202	10 18 6
STIFF CLAY	13	186	10 1 10
	14	173	9 6 10
SANDY CLAY	15	161	8 14 9
	16	151	8 3 10
	17	142	7 14 2
	18	135	7 5 11
	19	127	6 18 0
	20	121	6 11 1
FREE AND STONY . . .	21	115	6 4 10
	22	110	5 19 2
	23	105	5 14 1
	24	101	5 9 3
	25	97	5 4 3
	26	93	5 0 10
	27	90	4 17 1
	28	86	4 13 7
	29	83	4 10 4

Subsoils to which the Distances are applicable.	Distances between the Drains, in Feet.	Roods of Drains per Acre.	Cost per Acre.
Open	30	81	£4 7 5
	31	78	4 4 7
	32	76	4 2 0
	33	73	3 19 5
	34	71	3 17 1
	35	68	3 14 11
	36	67	3 13 0
	37	65	3 10 10
Irregular Beds of Gravel or Sand, and irregular open Rocky Strata	38	64	3 9 0
	39	63	3 7 2
	40	61	3 5 6

175. In using tiles and soles, as shown in fig. 54, p. 126, the width of the drain in the bed will be determined by the breadth of the soles. For tiles the internal diameter of which is from 3 to 4 in., the soles are commonly 7 in. in breadth. The length of the tile and sole is of course the same; but this length varies in different localities. The Ainslie machine tiles are 15 in. long when burnt; those made by the Marquis of Tweeddale's machine are 14 in.; but the more common length is 12 in. Machine-made tiles are in all cases much superior to those made by hand, being more thoroughly compressed, and consequently more dense. Containing *more* clay, they are still *thinner* than hand-made tiles. The 15-in. tiles are less subject to displacement in the drain, and less handling is, of course, wanted to make up any given length. The angular junctions are best formed by semicircular notches in the sides of the tiles into which the ends of the others are fitted. Tiles for main drains are commonly 4 in. wide, and 5 in. high in the clear, and the soles 9 or 10 in. in width, the thickness of both being about $\frac{3}{4}$ths of an inch. The ordinary price of tiles may be taken as about 20*s*. per thousand, and of the soles, half that of the tiles, or 10*s*. per thousand. To

the cost of the tiles an addition has to be made, averaging from 30*s*. to 40*s*. per acre, (the drains being 15 ft. apart,) for the expenses of carriage, loading and unloading, &c., which expenses do not appertain to the common loose stone drains as last described. With the addition of loose stones *over* the tiles, as shown in fig. 54, the cost will, of course, be considerably enhanced, as compared with that of common loose stone drains, nearly to the extent of the cost of the tiles, and the extra incidental expenses of from 30*s*. to 40*s*. per acre, the drains being 15 ft. apart. This will, however, form one of the most perfect, durable, and capacious drains that can be applied, and will command attention wherever these objects are sought with minor reference to cost.

176. Tiles in the form of complete tubes or pipes are, however, more perfect instruments of drainage than the separate soles and tiles, being less liable to derangement, and requiring only half the handling. Pipe-tiles, 2 in. in diameter, may be bought at the works at 18*s*. per thousand, and 15 in. in length; those 1½ in. in diameter at 15*s*., and 1 in. in diameter at 10*s*. per thousand. Mr. Stephens gives the following comparative summary of the cost, per acre, of the three kinds of drain, viz. stones, soles and tiles, and pipe tiles, the drains being 30 in. deep, and 15 ft. apart:—

	£	s.	d.
Loose stone drains	8	14	9
Sole and tile drains	7	10	8¾
Pipe-tile drains	5	8	9
Showing a saving by using			
Soles and tiles instead of stones, of . .	1	4	0¼
Pipe tiles instead of stones	3	6	0
Pipe tiles instead of soles and tiles . . .	2	1	11¾

Mr. Mechi states his expense of draining an acre of "strong clay land" (in Essex), the drains being 40 ft. apart, and average depth 4 ft., amounts to 2*l*. 9*s*. 6*d*. To this should be added about 1*l*. for the extra incidental expenses which his estimate does not include, and the total cost per acre

will be 3*l*. 9*s*. 6*d*. Without questioning the skill and experience of this gentleman, whose advocacy of thorough draining merits due appreciation, we are satisfied that he would find greater ultimate advantage by expending a little more money in making his drains more frequent and less in depth.

177. In comparing these several methods of forming drains, it is perhaps scarcely necessary to state the truth, that *first cost* does not afford an adequate test of efficiency and permanent economy. To obtain this, subsequent current expenses, and the resulting condition of the soil for agricultural purposes, must also be brought into the account, and will show the benefits to be derived from the use of pipe tiles still more forcibly.

178. The flat stone drains shown in figs. 53 and 55, are economical forms of construction in some localities, viz. where the required slabs are cheap and abundant. The shoulders, shown in fig. 55 as being left in the soil, may be in some cases better substituted by clearing the drain out level, and introducing two slabs of stone, meeting at the bottom, and having a stone wedged in between them at the top, the upper portion being filled in with loose stones. If the flat stones at the sides can be obtained 6 or 8 in. broad, and 1½ in. thick, at about 4*d*. per ton, an acre of land may be drained with drains 32 in. deep below the crowns of the gathered-up ridges, and laid at distances of 15 ft., at a cost of about 2*l*. 12*s*., exclusive of carriage of materials, and the ploughing by which the upper ridges are formed. Constructed as in fig. 55, if the covering flags can be procured 12 in. wide, and 2 in. thick, at the same rate per ton, the acre may be similarly drained for 8*s*. or 9*s*.

179. For the draining of bogs, the arrangement represented in fig. 57 is peculiarly applicable, all the materials being on the spot, as the whole drain is refilled with the peat itself, which is well known to resist the action of water with impunity. Provided the cutting of the drains

be done in summer, when the material quickly becomes dried, and sufficient time is allowed between the successive operations of cutting and refilling to effect the required consolidation, no better method is yet devised for effecting this kind of work. The liability of the moss in the bed of the drain to subside in detached parts, and with great irregularity, is certain to destroy any arrangement of tiles, pipes, or other artificial materials.

180. Another mode of forming drains with the natural materials, called *plug-draining*, has yet to be mentioned, rather to make our list complete than for any extended applicability of which it is susceptible. Plug drains are practicable only in subsoils of very firm clay entirely free from stones, and which never become thoroughly dry except by evaporation. Their use is further limited to lands, the occupation of which is that of permanent pasture. The usual form of open channel being formed in the clay, wooden blocks are introduced, which fit the lower part of the channel to a height of 8 or 10 in., and are convex or arched on the top. Upon these blocks, or *suters*, or *plugs*, the clay is returned and rammed down in a very careful and thorough manner. The plugs are then withdrawn, or drawn forward, for the formation of another length, and leave an open space or duct below for the passage of the water. In Gloucestershire, this kind of drain, 2 ft. deep, has been executed at from 4*d.* to 7½*d.* the rood of 6 yards, but the whole of the operations have to be conducted with extreme care, when the soil is free from frost or much wet, the ramming, moreover, requiring stout labourers, while much of pipe-draining may be performed by women and children, and the finished work is, after all, peculiarly liable, like all other drains formed with natural materials, to the destructive attacks of moles and other underground vermin.

181. These being the principal forms and constructions of land-drains, some notice of the successive operations to be carried on, and the implements to be employed, is re-

quired to complete our account of the draining of districts and lands.

182. The preliminary survey of the district to be drained having been made, and such indications of the nature of the soil as this survey affords noted, the next desideratum is, precise information as to the relative level or altitude, from a fixed datum, of every portion of the surface to be drained. These levels are obtained by the spirit-level in the usual manner, but they should be so complete as will enable us to lay down a *plan* of the district, with the *levels* of *equal altitude* marked upon it. These levels will appear as *lines* upon the map. Thus the highest point will be represented by a dot. The space around it, at one degree of altitude less, will appear as a continuous line encircling the dot. The space which has one degree of altitude less than this is represented by another encircling line around the preceding, and so on, down to the lowest altitude. These encircling lines, called *contour lines of equal altitude*, will, of course, be more or less irregular, according to the superficial character of the district. They were used in the French Survey, in 1818, having been suggested in an Essay read before the French Academy of Sciences so early as 1742, and since adopted for the Irish Survey in the year 1838. A precise idea of these lines may be formed, by supposing a block of stone, of an irregular conical form, to be immersed in a vessel of water. If the water be drawn off so as to lower its level equally, say one inch, at each successive discharge, the lines on which the water meets the surface of the cone will be the true contour lines of equal altitude. The *degree* of altitude to be adopted for each contour line will, of course, vary in amount, according to the prominence of the hills and the exactness required, being less in proportion as the district is flat or slightly undulating. From a map thus plotted, combining, as it does, a true plan and infinite sections of the district, any vertical section can at any time be accurately prepared without further reference to the ground,

while an immense advantage is obtained in the true indication of all brooks, and outcroppings of the substrata of the soil.

183. The levels being ascertained and recorded, the observations necessary to complete the information upon which the general arrangement of the drains can be determined have next to be made, by means of boring into and examining the structure of the subsoil at various points of the district. The tools, or *boring-irons*, employed for this purpose, consist principally of the *auger*, by which cylindrical holes are made in the soil, and their contents brought up to the surface; the *punch*, with which compact gravel and soft rock are perforated ready for the action of the auger; and the *chisel*, or *jumper*, with which, by the aid of sledge-hammers, the necessary holes are made in hard rocks which resist the auger and chisel. The auger is from 2 to 4 in. in diameter, and about 15 in. long in the shell. Its form is that of a cylinder, with a longitudinal opening throughout its length, and a sharp cutting edge or *nose* of steel secured to the entering end of it. The form of the punch is that of a pyramid of four sides, from 8 to 12 in. in length, and from 2 to 4 in. square on the base, which is the upper end of the tool when in use. The chisel is a flat tool, with a broad and cutting end, and is made of various sizes, according to the size of hole required. Each of these tools has a screw formed at the upper end, which will fit rods of iron made about 3 ft. long and 1 or 1¼ in. square, used to lengthen the apparatus when the hole becomes deeper than the length of the cutting tool. A cross handle of wood, fitted to a tapped socket, that fits upon the tools and rods, is used for the purpose of turning the augers.

184. When the nature of the subsoil has been ascertained by boring, and the arrangement of main and minor drains determined, the work of forming the drains is commenced by marking the lines upon the surface with poles, and driving stakes to indicate the intended position and

direction of the cuttings. A common garden line is then used to mark off the sides of the cuttings according to the width they are intended to have. The ground is then rutted with the spade along the line, and a rut is made at each side of the drain. From 20 to 30 yards are thus lined out at each stage: The different tools to be then employed will vary according to the structure of the subsoil to be removed.

185. For ordinary soils, such as clays, loams, and small gravel, and the usual combinations of these materials, the common spade, the ditcher's shovel, and foot and hand-picks, are the tools employed. The foot-pick has a cross handle of wood, and a tramp fixed at about 15 in. from the point of the tool, on which the foot of the workman is placed to drive it into the soil, and which forms a fulcrum on which stones or lumps of the hard dry clay are raised. The ditcher's shovel resembles a common spade, but is somewhat stronger, and rounded off on each side from the haft, forming a rounded point at the lower end. If the sides of the drain have a tendency to fall in before the work can be completed, they must be sustained by planks and short struts of timber wedged in between them. In order to test the correct dimensions of the drain, a gauge is useful, which consists of an upright stem, on which two or three cross-pieces are fitted to move up and down. The stem being graduated, these cross-pieces may be shifted and fixed so as to correspond with the intended limits of the cutting, and applied wherever thought necessary.

186. The uniformity of the fall of drains is tested with three staves, each consisting of an upright stem, and a cross-piece on the top fixed at right angles, so that the form of the instrument resembles that of the letter T. Two of these staves are made about 2 ft. in height, and the third one equal to 2 ft. added to the depth of the drain. The two shorter ones are held perpendicularly, one at each end of the drain, upon the surface of the ground, while the long one is shifted along the bed of the drain, and the

prominent or depressed points marked for correction. Besides these staves, a common mason's level, with a plumb line, is a very useful instrument for testing the inclination of the drains. Mr. Denton has designed a still more complete apparatus for this purpose, which he names the A level, from its resemblance to that letter in form, having a cross-shifting limb, by which the inclination of one of the legs is adjusted, so that a plumb line from the apex indicates the intended fall, one of the legs having a sliding vernier, and the other having cross hairs for ranging the levels to the end of the drain, with a graduated staff.

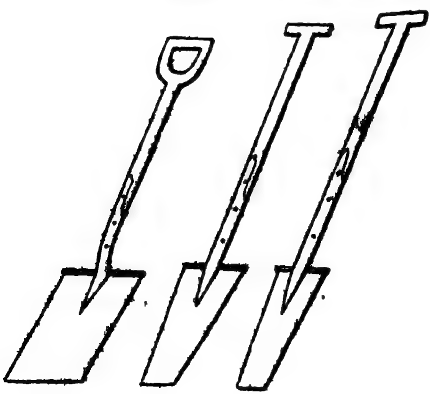
187. In the formation of loose stone drains, after the stones are assorted as to size, and deposited in the drains (for which purposes Mr. Roberton, of Roxburghshire, has introduced a very complete and portable form of harp or screen, provided with a movable tailboard), they are evenly distributed in the drain with a strong rake, and beaten down with a heavy beater, having a cross-handle for raising it. The best form of shovel for the stones is that known as the frying-pan, or lime shovel, having a raised rim around the hinder part of it, and being made of a capacious size.

188. The cutting of tile drains, requiring very exact work, is best performed with tools fitted peculiarly for it. Thus the narrow drain spade produces more perfect work in throwing out the loosened soil, and also trimming the sides of the drain, than the common spade. Pipe drains, being much narrower in the bed than any others, are best finished with small tools designed for the purpose. These are the narrowest drain spades, made only 3½ or 4 in. wide at the mouth, and having a stud or tramp in front for the heel of the workman, to assist in pressing the tool into the soil. Narrow hoes are also useful in removing small stones, &c., from the bed; and for removing any wet and loose earth that may accumulate in it after the cutting of the drain, a scoop formed like a long narrow hoe with raised sides is very effective, being, in use, drawn forward by the workman.

The bed of these drains may also be very nicely finished and adjusted with a trowel, formed with the edges parallel, and rounded only near the front.

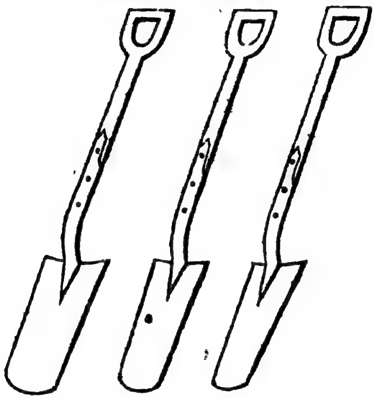
189. The objects to be attained in draining implements are strength, combined with lightness, and handiness; width, sufficient to remove at one cut all the soil required to be taken out of a drain at any one part of it; such a shape of the blade, that it shall, when lifted, raise the earth cut, leaving the least possible quantity of broken earth to be removed subsequently. Spades of various widths are needed for cutting the parts of a drain, so that it shall be finished with a regular tapering section with a top width sufficient to enable the drainer to work in it, and a bottom width only equal to receive the material to be deposited. Many implements have been introduced of various shapes, and some of them possessing considerable merit; but we have space here to notice only the two principal sorts of drain spades, which have been found in practice superior to all others for working in common soils, and of increased superiority in proportion to the difficulty which the material to be excavated presents to ordinary operations. Of these, the "Markly spade," introduced by Mr. Darby, represented

Fig. 61. *Fig.* 62. *Fig.* 63.



of different sizes in figs. 61, 62, and 63, is admirably formed for removing the lowest 16 or 18 in. of a drain, and has proved its superiority in "shape and make" as adopted for cutting through and lifting out a hard gravel or rocky bottom. Figs. 64, 65, and 66, represent a kind of spade ori-

Fig. 64. *Fig.* 65. *Fig.* 66.



ginally used in Kent, and since introduced into Rosshire, and other parts of Scotland, where it has been found to improve the method of cutting the drains, and also to cheapen their formation to a material extent. With such implements as these, a drain 10 to 12 in. wide at top, 3 in. wide at bottom, and 36 to 40 in. deep, may be opened by a single cut from each of these sizes.* Drains 40 to 48 in. deep require a double cut in width and depth with the largest of the three spades.

190. Bog drains are formed with some tools of peculiar form, which may be noticed. Thus the surface turf is cut along the lines of the intended drain with an edging iron of a crescent-like form, and sharpened round its outer edge. For cutting the turf out, a broad-mouthed shovel is used.

* Mr. Spooner's evidence—"Minutes of Information," collected by the General Board of Health, 1852.

The moss, being cut into square peats with this shovel, is lifted from the drain with a three-pronged fork made for the purpose, or if footing be found for the workmen, the peats may be neatly cut from the bed, and thrown out with spades fitted with the handle at a large angle to the spade, which may thus be conveniently used in a horizontal position.

191. In soils where peat is plentiful, this material is sometimes cut or compressed into form, and baked so as to constitute open ducts when laid together in the drain Mr Calderwood, of Ayrshire, introduced, some years ago, a tool fitted to cut peats into a massive semi-cylindrical form by one cut, and without any waste of material, the hollow in one peat fitting the exterior of another It is said that one man accustomed to the work can cut from 2000 to 3000 of these peats in a day They are afterwards dried in the sun, and stacked till required. Several highly-ingenious machines have been invented for forming peat tiles, and also for moulding the pipe tiles of clay of various forms, to secure ready and accurate joints, by which improvements the cost of production has been within late years most materially reduced.

192. Some part of the work of cutting drains has, at various times, been attempted with ploughs of different forms and construction, fitted, wherever they are applicable, to effect some economy in the cost of labour for the work. Ploughs to facilitate the cutting of drains have been in use for many years in districts where alluvial clays prevail, and when used, they have been found to economise the cost of drainage considerably; but owing to the great number of horses (from 8 to 12) required to work them, and the difficulty first experienced by ordinary farm-servants in trying to manage so many horses and such large implements, the use of them has been heretofore much restricted.

193. An implement has, however, been introduced, which, as a draining plough, has far surpassed all previous efforts and which accomplishes the entire work of opening the

ground, depositing the pipes, and making good again in an admirable automatic style. This implement is the "draining plough" of Messrs. Fowler, Harris, and Taylor, of Temple Gate, Bristol, and will be found described and illustrated in the Second Part of the Rudimentary Treatise on Draining.

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